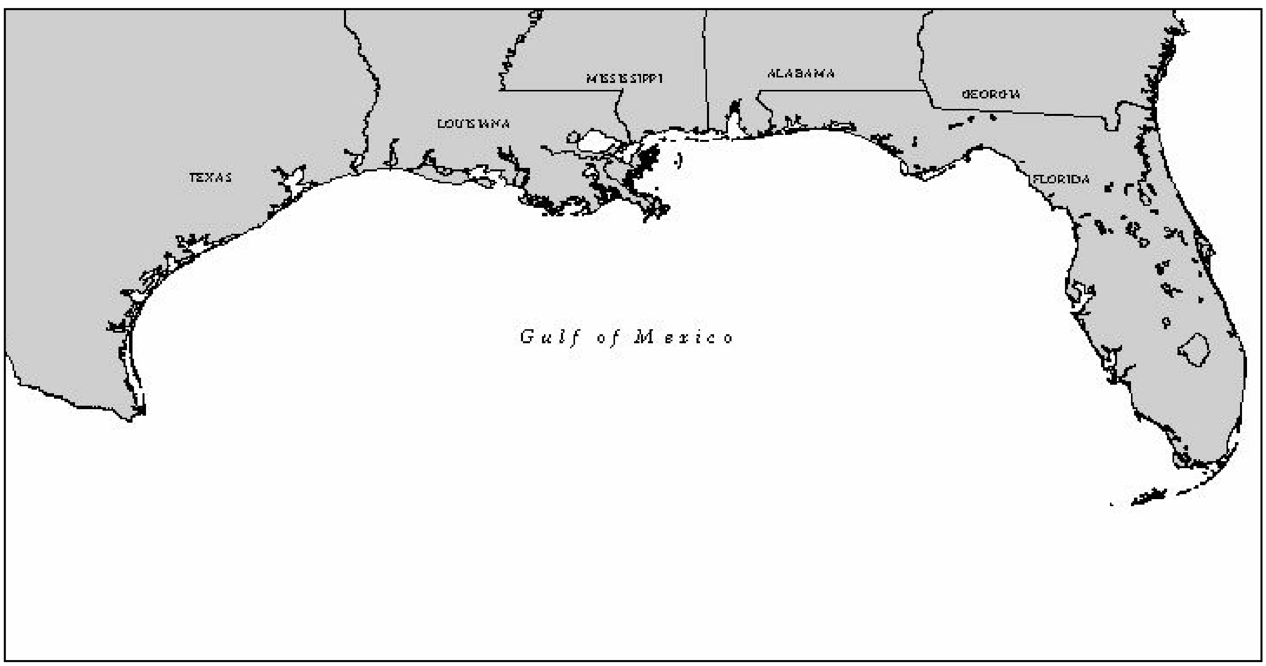
OCS Study
MMS 2004-072

Gulfwide Emission Inventory Study for the Regional Haze and Ozone Modeling Effort

Final Report



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

OCS Study
MMS 2004-072

Gulfwide Emission Inventory Study for the Regional Haze and Ozone Modeling Efforts

Final Report

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1. EXECUTIVE SUMMARY

The Minerals Management Service (MMS) is responsible for assessing the potential impacts of air pollutant emissions from offshore oil and gas exploration, development, and production sources in the Outer Continental Shelf (OCS). This responsibility is driven by the OCS Lands Act, which directs the MMS to regulate OCS emission sources to assure that they do not significantly affect onshore air quality. The MMS air quality regulations are contained in 30 CFR 250.302 through 304. In particular, MMS is responsible for determining if platform and other emissions from the Gulf of Mexico OCS influence the ozone attainment (or nonattainment) status of onshore areas in Louisiana and Texas. This responsibility was mandated by the 1990 Clean Air Act Amendments (CAAA). In addition, the 1990 CAAA requires MMS to coordinate air pollution control activities with the State regulatory agencies. Thus there will be a continuing need for emission inventories and modeling in the future, especially with the implementation of the 8-hour ozone standard. The future area of interest is not just Louisiana and Texas, but also includes Mississippi, Alabama, and Florida. To assess the emissions of offshore oil and gas platforms and their associated emissions, the MMS conducted some limited emission inventories in the Gulf of Mexico in the 1980s. In 1991 the MMS sponsored a regional ozone modeling effort conducted by the U.S. Environmental Protection Agency (EPA) using the Regional Oxidant Model (ROM). The Gulf of Mexico Air Quality Study was initiated that same year, and activity data for a Gulfwide emissions inventory were collected for a one-year period in 1991-92.

The MMS' Gulf of Mexico Outer Continental Shelf Regional office sponsored this project, the *Gulfwide Emission Inventory Study* (MMS Contract No. 00-01-CT-31021), which builds upon these studies with the goal of developing a base year 2000 air pollution emissions inventory for all OCS oil and gas production-related sources in the Gulf of Mexico, including non-platform sources. Pollutants covered in this inventory are the criteria pollutants—carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter-10 (PM_{10}), $PM_{2.5}$, and volatile organic compounds (VOC); as well as greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

To develop the inventory, the Gulfwide Offshore Activities Data System (GOADS) was created, which was used to collect monthly activity data from platform sources. The activity data were combined with the most recent emission factors published by the EPA, and Emission Inventory Improvement Program (EIIP) emission estimation methods to develop a comprehensive criteria pollutant and greenhouse gas emissions inventory. Non-platform emission estimates were developed for sources such as the Louisiana Offshore Oil Platform (LOOP), commercial marine vessels, and helicopters. Diurnal emission profiles were also developed for the major categories of sources inventoried. The profiles will allow inventory emission estimates for a given category to be temporally allocated, across a 24-hour time period, on a 1-hour basis. Ultimately, State agencies will use this information to perform modeling for ozone and regional haze for use in their State Implementation Plans (SIPs).

2. INTRODUCTION

Measurements of ozone concentrations in onshore areas of Texas and Louisiana periodically exceed the national standard for one-hour ozone in nonattainment areas, with some observations nearly three times the national standard. Shoreline and inland locations in Texas and Louisiana could potentially be influenced by emission sources in the Gulf of Mexico. The Minerals Management Service (MMS) is responsible for determining if air pollutant emissions from Outer Continental Shelf (OCS) oil and natural gas platforms and other sources in the Gulf of Mexico influence the ozone attainment and nonattainment status of onshore areas. Ozone forms in the presence of sunlight from the reaction of volatile organic compounds (VOC) and oxides of nitrogen (NO_x).

The Clean Air Act Amendments of 1990 (CAAA Title VIII, Sec 801(b)) specifically mandate that MMS conduct a research study to assess the potential for onshore impacts of certain types of air pollutant emissions from offshore oil and gas exploration, development, and production in regions of the Gulf of Mexico. This mandate grew out of concerns regarding the cumulative onshore impacts of air pollutant emissions from more than 3,000 offshore facilities in the central and western Gulf of Mexico. MMS launched a series of studies, beginning in the 1980s, to assess the emissions of offshore oil and gas platforms and their associated emissions.

MMS undertook the *Gulf of Mexico Air Quality Study* (GMAQS) to assess the potential impacts of emissions from oil and gas exploration, development, and production in the OCS region of the Gulf of Mexico. The overall goal of the study was to assess, through computer simulation modeling, the effects that OCS development has on ozone concentrations in the onshore areas of Texas and Louisiana that are designated by the U.S. Environmental Protection Agency (EPA) as nonattainment for one-hour average ozone. The study covered many types of offshore emission sources, focusing on oil and gas production platform emissions. Results are summarized in the 1995 report, *Gulf of Mexico Air Quality Study* (U.S. DOI, MMS 1995).

MMS is currently sponsoring several additional atmospheric sciences studies, including two air quality emission inventory projects that affect only platforms within 100 kilometers (km) of the Breton National Wilderness Area in the Gulf of Mexico. Through an Office of Management and Budget-approved Information Collection Request, MMS required affected platform operators to collect activity data used in both studies. As part of its program to collect activity data, a Visual Basic program was developed, known as the Breton Offshore Activities Data System (BOADS), for platform operators to submit activity data on a monthly basis. Activity data were collected for a number of production platform emission sources and used to estimate air pollutant emissions on a monthly basis (Coe et al. 2003).

3. DATA COLLECTION

3.1 INTRODUCTION

To develop a base year 2000 inventory of criteria pollutant and greenhouse gas emissions for all OCS oil and gas production-related sources in the Gulf of Mexico, MMS collected activity data from platform operators during the year 2000. On June 30, 1999, MMS published Notice to Lessees and Operators (NTL) 99-G15 to inform operators about the mandatory data collection and a meeting to learn more about the data request. Affected operators are lessees and operators of federal oil, gas, and sulfur leases in the Gulf of Mexico OCS region.

This section of the report outlines the steps that MMS and ERG, Inc. took to collect the data, including modifying and testing the data collection software, meeting with and training platform operators, and answering questions about data collection. Activity data were collected over one calendar year (year 2000) and were used to calculate and archive emissions data using the most current emission factors and calculation methods.

3.2 EXPANSION AND TESTING OF THE BOADS DATA COLLECTION SOFTWARE

ERG expanded the BOADS data collection software to add several emission sources: mud degassing, pneumatic pumps, and pressure/level controllers. Two emission sources—losses from flashing and fugitives—already existed in BOADS, but were modified for the Gulfwide Offshore Activities Data System (GOADS). These modifications were made to improve the reporting of flashing occurences, and to simplify the reporting associated with fugitives (only annual reporting is needed, not monthly). Another parameter, sales gas composition, was added to the Structure Screen for operators to report composition of gas processed and transferred off the structure.

The GOADS data collection software was designed to mimic the BOADS interface, thus reducing operator retraining. ERG expanded the BOADS data collection software, written in Visual Basic, to collect additional activity data that would be necessary to calculate the additional pollutants. To reduce duplication, ERG designed GOADS to import BOADS data. The objective was to collect, perform quality control, and archive activity data from platform sources that emit carbon monoxide (CO), sulfur dioxide (SO_2), NO_x, particulate matter-10 (PM_{10}), $PM_{2.5}$, VOC, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Ammonia emissions are not included because there were no selective catalytic reduction (SCR) or selective noncatalytic reduction (SNCR) air pollution controls reported. SCR and SNCR are NO_x emission controls for combustion sources and may be sources of ammonia emissions, because ammonia, or an ammonia derivative such as urea, is used as the reducing gas to react with NO_x to form molecular nitrogen and water. SNCR differs from SCR in that no catalyst (a base metal or zeolite) is used.

To add an emission source, ERG merely added it to the already existing drop-down menu. For each new emission source, an equipment screen was created that contained fields for the parameters to be recorded. As an example, the pneumatic pumps and pressure/level controllers equipment screens require operators to enter parameters such as the manufacturer, model, hours operated, and equipment elevation. For details on equipment parameters, see section 2.2 of the User's Guide for the Gulfwide Offshore Activities Data System for Air Quality (http://www.gomr.mms.gov/homepg/regulate/environ/airquality/goad.html).

3.3 WORKING WITH USERS

A workshop was held in New Orleans on November 15, 1999 to discuss and explain the Gulfwide study information collection and reporting procedures, the pollutants to be covered, and the reasons the Gulfwide study was undertaken**.** To assist users in submitting data, ERG and COMM Engineering staff provided GOADS Inventory Data Sheets that identified the type of data to be entered into the GOADS software. The sheets included company/facility data, parameters for emission sources, and a summary of equipment parameters to be recorded to calculate annual fugitive emissions for the facility. COMM Engineering staff also distributed a handout to participants that contained standard units of measure, calculation of exit velocity, methods to determine fuel usage, stack temperature ranges, and frequently asked questions.

The "User's Guide for the Gulfwide Offshore Activities Data System (GOADS) for Air Quality" (Wilson et al. 2001) was the primary source of information for operators. The guide was made available to all users via the MMS web site, where it could be downloaded and printed. The guide contains instructions on installation, starting and exiting GOADS, creating and editing data, quality control, and saving and backing up files.

A second workshop was held in New Orleans on March 15, 2001. ERG staff walked operators through installing the software, entering data, and reporting data. The purpose of this workshop was to allow users to install and use the software firsthand, and ask questions. ERG also directed operators to other sources of information for future questions.

3.4 OPERATOR USE OF GOADS SOFTWARE TO COLLECT DATA

Once operators obtained the software and attended the training workshops, they were ready to begin entering data. MMS communicated with operators through the MMS web site using Frequently Asked Questions (FAQs) and electronic mail (e-mail). ERG drafted FAQs that were distributed at the second workshop, posted on the Web site, and periodically updated. The designated MMS support staff were Dr. Chester Huang, Mr. Joe Perryman, and Mr. YP Desai.

3.5 QUALITY ASSURANCE/QUALITY CONTROL

ERG programmed automatic quality assurance (QA) procedures into the software in an effort to minimize the submittal of incomplete and erroneous activity data by the platform operators. ERG requested that operators submit a printout of their Quality Assurance Summary Form along with their monthly activity files. The QA Summary focuses on identification of critical data that the operators need to complete prior to submitting their data to MMS.

The software also automatically runs a series of quality control (QC) checks on the data when the operator saves it. If the operator leaves a field blank, provides data that are out of range, or enters a value that is not consistent on a month-to-month basis, an error message will appear. The operator can either correct the problem, override the QC check (and provide a comment), or ignore the message and save the changes. When operators entered data that appeared in the QC results or on the QA Summary Form, ERG attempted to reconcile the missing, atypical, or suspect data by reviewing the comments, contacting the operators, or developing surrogate data as described in Section 4 of this report. Surrogate data were developed primarily for the stack parameters requested for the emission release point for each piece of equipment. These parameters are needed for air quality modeling efforts. The surrogates were developed based on industry averages, and through discussions with MMS.

4. QUALITY ASSURANCE/QUALITY CONTROL

4.1 INTRODUCTION

Platform operators submitted data files and QA Summary Forms generated by the GOADS software. Ninety-three companies submitted data for 3,154 active or inactive platforms (combination of complex ID and structure ID). Included in the submittal were 1,150 survey records and 35,198 structure records. A unique survey record is a combination of user ID and month. A unique structure record is a combination of complex ID, structure ID, and month. A total of 239 unique monthly and annual files were provided by 93 companies.

This section summarizes the data received, the steps ERG took to review the monthly GOADS data for completeness and accuracy, the types of errors encountered. Also discussed in this section are the procedures used to correct and gap-fill missing data, including stack parameter data provided by the operators. When operators failed to enter data or entered data that were atypical or suspect, ERG attempted to reconcile the data by reviewing the comments, contacting the operators, or developing surrogate data.

4.2 CHECKING FILE INTEGRITY AND MATCHING QA SUMMARY

MMS sent 239 unique data files to ERG primarily on two compact disks (CDs) and all files were logged onto a tracking sheet. The first CD (CD-1) contained 81 files and the second (CD-2) contained 237 files (including 80 duplicate/replacement files for files on CD-1). An additional CD was sent containing a replacement GOADS submittal with 12 files, and a new submittal (1 file) was provided via file transfer protocol (FTP). All electronic data were in the prescribed Microsoft Access 2000 database that was created by the GOADS software.

ERG checked file integrity to verify that the file submitted could be opened, and that it matched its QA Summary Form (same user, structure, and complex IDs). ERG was able to open and review all of the files provided. Companies were also required to submit a hardcopy of their QA Summary Form. Of the 239 files submitted, 222 were accompanied by a hardcopy of their QA summary results (93%). For the submittals missing hard-copy QA Summary Forms, ERG was able to print the form for review.

4.3 EQUIPMENT SUMMARY CHECKS

Each GOADS submittal contained templates for up to 23 tables. The majority of these tables covered specific equipment types (amine units, boilers, etc.). However, additional user-, structure-, and survey-level tables, as well as quality assurance tables, were also appended into one composite database. Primary keys (user ID, month, year, complex ID, structure ID, and equipment ID) were retained in all tables to ensure that no duplicate data were added.

4.3.1 User-Level Summary

The first data entry page in GOADS is for user information. The user ID should be the MMS company number assigned by MMS; however, at least 10% of the user IDs submitted were incorrect when checked against the MMS master lease and company lists. ERG prepared a matrix of submitted vs. "correct" user IDs, and identified IDs that are incorrect. The official MMS list of companies, leases, and platforms was retrieved from the MMS Web site: http://www.gomr.mms.gov/homepg/pubinfo/freeasci/platform/freeplat.html.

ERG used these master lists to check and correct the lease, company, and platform IDs. Additionally, ERG checked and corrected the locational data (latitude/longitude pairs) for each platform.

4.3.2 Survey-Level Summary

After entering the user ID, the next data entry page in GOADS is for a new survey. There are two types of surveys that can be submitted: 1) the monthly equipment data set, and 2) annual submittals for fugitive information. A survey contains the activity parameters by equipment type (including fugitives), user information, and structure-level information. Ideally, 13 submittals are to be completed for each platform.

All 93 companies submitted survey-level data. Nearly 85% of the submittals completed all 13 surveys. The remaining 14 companies submitted between 3 and 12 surveys, which may indicate changes in ownership during the inventory year.

4.3.3 Structure-Level Summary

For each survey, the user was required to enter platform-level data that includes location coordinates, fuel usage, and status (active or inactive for that month). A total of 35,198 records were submitted. Of this total, 31,473 records were labeled as "active" (89%).

All 93 companies submitted structure-level data, and the number of unique surveys was the same as in the survey table (85% completed all 13 surveys). Files for 3,154 unique active or inactive platforms (combination of complex ID and structure ID) were submitted. Forty-three (43) platforms submitted survey information for more than one user ID. Possible explanations may be use of incorrect IDs, or a change in ownership. After numerous QA/QC checks to remove incorrect or duplicate structure-level records, a total of 3,096 unique active or inactive platforms remained.

4.3.4 Equipment-Level Summary

Equipment information and activity-level data for 15 different types of equipment can be populated for each platform-survey combination. A list of all the platform equipment submitted per equipment type was compiled. This composite list includes 2,873 unique, active, platforms, indicating that 223 platforms were inactive, or were "satellite" platforms with no emission sources (operators were asked to include records for these platforms regardless).

4.4 QA/QC CHECKS

Part of the QA task for the GOADS submittals was to identify incorrect and missing data, and to correct and populate the missing information with surrogates. Early into the QA analysis, all of the equipment survey data were appended into single database; a number of QA steps to identify the missing data were then performed on all the data to boost efficiency. Once the missing data were identified, MMS-approved surrogate values and approaches were used to provide as complete an inventory as possible.

Six types of data analyses were performed: 1) pre-processing of the data; 2) equipment survey consistency; 3) data range checks; 4) stream analysis between certain equipment; 5) applying surrogate values; and 6) post-processing of surrogates.

4.4.1 Pre-Processing

Three pre-processing steps occurred before the rigorous data analysis could begin. First, the activity status of each survey was confirmed. Second, the reported number of operating hours for each piece of equipment was checked to make sure it did not exceed the maximum number of hours in the month. Third, the reported fuel usage at the equipment level was compared to the maximum capacity of the equipment and the reported fuel usage for the entire platform.

Operators had the opportunity to identify a platform as being either active or inactive for each of the monthly surveys. Inactive data are not considered for emissions calculations, so this step is extremely important. For equipment surveys that request hours of operation, platform surveys were labeled as active if any of the equipment the operating hours were greater than zero. Conversely, a platform survey was labeled as inactive if all of the equipment operating hours were zero.

The Flare and Vent Occurrence tables were reviewed to help verify the activity status of each survey, although hours of operation are requested in the Flare and Vent equipment tables. A platform survey was considered *active* and emissions were calculated if the flare and vent hours of operation are zero, but there was an upset record in the Flare or Vent Occurrence tables. This scenario is possible because the operators were asked to report operating hours, excluding process upsets, and also number of upsets that occurred for each survey month.

Platform surveys were also considered active based on a review of the following equipment data if: 1) in the Fugitive equipment table, the component count provided was greater than zero; 2) in the Loading and Losses from Flashing equipment tables the throughputs were greater than zero; or 3) in the Mud Degassing equipment table, the drilling days per month were greater than zero.

For the equipment surveys, over 86% of the equipment-level records were identified as being entered with the correct status. Less than 3% of the equipment records were changed from inactive to active. The Fugitive table required the most of these changes, with nearly 67% of the records requiring a status change. All of the other equipment tables only had less than 1% of the records requiring this status change. The remaining 11% of the equipment records were changed from active to inactive. In the Vent table, over 56% of the records required a status change, while the other equipment tables had up to 30% of the records requiring this status change.

For each month, operating hours were to be provided for most types of equipment. A typical error would be to exceed the maximum hours possible for each month. Similarly, hours of operation may not have been populated. For both of these errors, data were corrected in the same manner by populating with the maximum number of hours possible. The maximum number of hours for months with 31 days (January, March, May, July, August, October, and December) is 744; for months with 30 days (April, June, September, and November), the maximum number of hours is 720. In year 2000, the maximum amount of hours for February (29 days) is 696. Overall, 4% of the Hours of Operation data submittals needed to be corrected.

The last pre-processing step focused on the reported fuel usage. Platform operators provided estimates of total fuel used for each month for the entire platform, and for each boiler/heater/burner, diesel engine, natural gas engine, natural gas turbines, and drilling operation. Additionally, operators were asked to provide fuel equipment parameters such as hours operated, fuel usage rate (average and maximum), operating horsepower (average and maximum), and heat input rate.

The average and theoretical maximum fuel usage for each reported boiler/heater/burner, diesel engine, natural gas engine, and natural gas turbine was calculated by multiplying the hours operated by the average or maximum heat input or fuel usage rate and operating horsepower, and dividing by the fuel heating value. These values were compared to the total fuel used value submitted for each month. When the reported fuel usage exceeded the theoretical maximum fuel usage, the submitted values were replaced with the calculated theoretical maximum fuel usage values. When the reported fuel usage fell below calculated average fuel usage value by more than 15%, the submitted values were replaced with the calculated average fuel usage values.

After correcting the individual equipment fuel usage values, the reported monthly total fuel used for the platform was compared to the sum of the individual pieces of equipment by fuel type. For the most part, the goal of this comparison was to make the two reported totals somewhat consistent. If the sum of reported (or corrected) fuel usage in the equipment tables was greater than the reported platform total, the platform total was revised to equal the equipment sum. If the reported platform total was not populated, it was populated with the equipment sum.

4.4.2 Equipment Survey Consistency

A platform may contain several pieces of equipment that operate year-round, but data parameters may not have been populated for every month. In this situation, the entire platform equipment dataset was examined. For example, 11 of the 12 monthly surveys may be populated for a boiler with the same fuel heating value, while one month, although marked active, may be null or provide a different fuel heating value. The missing or different value was populated to match the other platform equipment surveys if ERG believed a data entry error occurred.

Certain parameters will not vary on a monthly basis, such as stack outlet inner diameter and equipment elevation, while other parameters can vary monthly, such as fuel usage rate and hours of operation. For each of the non-varying parameters, the data were grouped at the platform-equipment level to determine where inconsistent data may have been entered; data entry errors were then corrected.

4.4.3 Data Range Checks

After the equipment surveys were checked for survey consistency, the parameters were checked to ensure that they were within an acceptable data range. For example, some operators mistakenly entered incorrect fuel heating values. Natural gas has a fuel heating value on average of 1,050 Btu/scf. However, some equipment surveys had entered 105 Btu/scf as their fuel heating value, or even 19,300, which is the average fuel heating value of diesel fuel (in units of Btu/lb, however).

This type of error would not be detected through the equipment survey consistency step if all the incorrect data were entered the same for each survey. It is believed that some operators did not run the QC check correctly or at all within the GOADS program; this would explain why these incorrect data were not flagged initially.

The ranges were checked for the fields listed in Table 4-1. These ranges are based on the relationship between the parameters noted in Table 4-1 (e.g., actual fuel usage rate cannot exceed the reported maximum fuel usage rate), and typical fuel and control device efficiency values. The exhaust outlet inner diameter and number of flare and vent occurrences data fields required the most corrections (21.4%, 18.3%, and 18%, respectively), while the operating horsepower needed the fewest corrections (<0.10%).

Table 4-1. Fields and Range Check Values.

Field	Range Check
API Specific Gravity	Minimum value: 9 degrees API
Average Liquid Height	Not to exceed outlet height
Flare Efficiency	90 and 99%
Fuel Heating Value	Natural gas: 500 to 1500 Btu/scf Diesel: 18,000 to 22,000 Btu/lb
Fuel Usage Rate	Not to exceed maximum fuel usage rate
Fuel H_2S Content	0 to 5 ppmv
Fuel Sulfur Content	0 to 5 percent
Heat Input Rate	Not to exceed maximum heat input rate
Inner Diameter	Greater than 5 inches
Number of Occurrences	Must match upsets in Flare or Vent tables
Operating Horsepower	Not to exceed maximum rated horsepower
Stack Angle	Between 0 and 360

4.4.4 Stream Analysis Between Certain Equipment

Certain pieces of equipment may not be vented locally, but rather piped downstream to a vent or flare. It is important for the downstream exhaust vents to be correctly identified; otherwise the calculations may overestimate emissions. Additionally, the low-pressure vent/flare ID field must include the necessary prefix characters of "VEN" if directed to a vent or "FLA" if directed to a flare.

The Amine Unit, Glycol Dehydrator, Loading, Losses from Flashing, Pneumatic Pumps, and Storage Tanks equipment may exhaust gases locally or downstream. If the Vent or Flare ID is populated in these tables, then a downstream analysis was performed on the Vent or Flare equipment tables to verify their existence. For Vent or Flare ID's that could not be traced to an existing active vent or flare, the survey was updated as to being vented/flared locally.

Over 75% of the data records were labeled incorrectly for the applicable tables. The Losses from Flashing equipment table required the highest number of data corrections (33%).

4.4.5 Applying Surrogate Values

Surrogate values were used to populate missing stack parameters that are needed for air quality modeling. These parameters are listed in Table 4-2 by equipment type. As shown in Table 4-2, surrogate values could be calculated for exit velocity and exhaust volume flow rate from the submitted data. Other surrogate data were developed from industry averages, and through discussions with MMS.

4.4.6 Post-Processing of Surrogates

After all the missing data have been populated through quality assurance checks and surrogates, two calculations were performed to check the overall quality of the data. The first calculation was for exit velocity; the second was for total fuel usage. Both of these recalculations were checked against the submitted data.

Table 4-2. Surrogate Stack Parameters Used to Supplement GOADS Data.

Unit	Field	Default Value
Amine Unit	Elevation (above sea level)	50 ft
Amine Unit– ventilation system for acid gas from reboiler	Exit velocity (ft/sec)	Calculated with AMINECalc[a]
Amine Unit– ventilation system for acid gas from reboiler	Exit temperature	110 ^oF
Amine Unit–ventilation system for acid gas from reboiler	Combustion temperature	1832 ^oF
Boiler/heater/burner	Elevation (above sea level)	50 ft
Boiler/heater/burner – exhaust System	Exit temperature	400 ^oF
Boiler/heater/burner – exhaust system	Outlet orientation	0 degrees
Boiler/heater/burner – exhaust system	Outlet diameter	12 inches
Boiler/heater/burner – exhaust system	Exit velocity	Calculated
Diesel Engine	Elevation (above sea level)	50 ft
Diesel Engine	Max rated fuel use	7000 Btu/hp-hr
Diesel Engine	Avg fuel use	7000 Btu/hp-hr
Diesel Engine– exhaust system	Outlet height	7 ft above engine
Diesel Engine– exhaust system	Exit velocity	Calculated
Diesel Engine– exhaust system	Exit temperature	900 ^oF
Diesel Engine– exhaust system	Outlet orientation	0 degrees
Diesel Engine– exhaust system	Outlet diameter	12 inches
Flare	Combustion temperature (excluding upsets)	1832 ^oF
Flare	Stack orientation	0 degrees
Flare	Outlet diameter	12 inches
Glycol Dehydrator	Elevation (above sea level)	50 ft
Glycol Dehydrator– flash tank	Temperature	120 ^oF
Glycol Dehydrator– flash tank	Pressure	60 psig
Glycol Dehydrator– ventilation system	Exit temperature	GLYCalc default (usually 212 ^oF)[b]

Table 4-2. Surrogate Stack Parameters Used to Supplement GOADS Data (Continued).

Unit	Field	Default Value
Glycol Dehydrator– ventilation system	Outlet orientation	0 degrees
Glycol Dehydrator– ventilation system	Flare feed rate (scf/hr)	Calculated with GLYCalc[b]
Glycol Dehydrator– ventilation system	Combustion temperature	1832 ^{o}F
Glycol Dehydrator– ventilation system	Condenser temperature	110 ^{o}F (or calculated with GLYCalc)[b]
Glycol Dehydrator– ventilation system	Condenser pressure	14.8 psia
Loading – barge	Elevation (above see level)	0
Loading – ventilation system	Exit temperature	70 ^{o}F
Loading– ventilation system	Outlet orientation	0 degrees
Loading– ventilation system	Outlet diameter	3 in.
Loading– ventilation system	Exit velocity	Calculated
Loading– ventilation system	Flare feed rate	Calculated (use loading exhaust vol. flow rate if controlled by flare)
Loading– ventilation system	Combustion temperature	1832 ^{o}F
Losses from Flashing– ventilation system	Exhaust volume flow rate	Calculated
Losses from Flashing– ventilation system	Exit velocity	Calculated
Losses from Flashing– ventilation system	Exit temperature	70 ^{o}F
Losses from Flashing– ventilation system	Outlet diameter	Use Tank Vent Outlet Diameter
Natural Gas Engine	Max rated fuel usage	7000 Btu/hp-hr
Natural Gas Engine	Avg fuel usage	7000 Btu/hp-hr
Natural Gas Engine– exhaust system	Exit velocity	Calculated
Natural Gas Engine– exhaust system	Exit temperature	4-cycle rich burn: 1100 ^{o}F
Natural Gas Engine– exhaust system	Exit temperature	2-cycle lean burn: 700 ^{o}F
Natural Gas Engine– exhaust system	Outlet diameter	12 inches
Natural Gas Turbine	Max rated fuel use	10,000 Btu/hp-hr
Natural Gas Turbine	Avg fuel use	10,000 Btu/hp-hr

Table 4-2. Surrogate Stack Parameters Used to Supplement GOADS Data (Continued).

Unit	Field	Default Value
Natural Gas Turbine– exhaust system	Exit velocity	Calculated
Natural Gas Turbine– exhaust system	Outlet diameter	12 inches
Natural Gas Turbine– exhaust system	Exit temperature	1000 ^oF
Pneumatic Pumps	Elevation (above sea level)	50 ft
Pneumatic Pumps– ventilation system	Exit velocity	Calculated
Pneumatic Pumps– ventilation system	Exit temperature	70 ^oF
Pressure/level Controllers	Elevation (above sea level)	50 ft
Storage tank – General Information	Roof Height above Shell (ft)	0.0625*(Tank Diameter, ft / 2)
Storage tank– ventilation system	Exit velocity	Calculated
Storage tank– ventilation system	Exit temperature	70 ^oF
Storage tank– ventilation system	Outlet orientation	0 degrees
Storage tank– ventilation system	Flare feed rate	Calculated (or use the calculated storage tank exhaust vol. flow rate)
Vent	Outlet elevation (above sea level)	50 ft
Vent	Outlet diameter	Calculated (average of submitted data)
Vent	Exit temperature	70 ^oF
Vent	Outlet orientation	0 degrees
Vent– upsets	Exit temperature	70 ^oF

[a] AMINECalc is released by the Gas Technology Institute as part of the AIRCalc Air Emissions Inventory Report Management Software Program (GTI 2001)

[b] GLYCalc is released by the Gas Technology Institute, formerly the Gas Research Institute (GRI) (GTI 2000)

5. DEVELOPMENT OF THE EMISSION INVENTORY

5.1 INTRODUCTION

The goal of the current study is to develop criteria pollutant and greenhouse gas emission inventories for all oil and gas production-related sources in the Gulf of Mexico. To achieve this goal, ERG revised the draft the Breton study Oracle database management program (DBMS) to create the Gulfwide Oracle DBMS. The Gulfwide DBMS imports the activity data described in Section 3 of this report, then applies emission factors to calculate emissions from platform sources in the Gulf of Mexico. This section of the report concentrates on efforts to revise the Breton study DBMS to create the Gulfwide study DBMS.

Using the Breton study DBMS as the starting point for calculating the Gulfwide emissions for the year 2000, ERG added calculation routines for several equipment types, added greenhouse gas emission factors to correspond to the available activity data, updated emission factors, and corrected errors.

The expanded database calculates emissions of CO, SO_2, NO_x, PM_{10}, $PM_{2.5}$, VOC, CO_2, CH_4, and N_2O, which contribute to regional haze, ozone, or greenhouse gas effects. Ammonia emissions were investigated, but are not expected from these emission sources.

The final Gulfwide study Oracle DBMS contains platform activity data and other data needed to calculate Gulfwide emissions, as well as non-platform emission estimates. Non-platform activity data and calculation methods are discussed in Section 6 and the appendices of this report. Figure 5-1 illustrates the flow of information into and out of the Oracle database.

5.2 EXPANSION OF THE DRAFT BRETON STUDY ORACLE DBMS

ERG refined and expanded the existing procedures in the draft Breton DBMS and created the GOADS DBMS. Specifically, ERG completed the following steps to improve and expand the Breton DBMS:

- Examined each calculation and corrected mathematical and typographical errors;
- Added emission factors and calculation routines for new equipment types;
- Added calculations to estimate additional pollutants for all equipment types;
- Updated emission factors with the latest information in *AP-42* (EPA 2002);
- Standardized the calculations to be consistent with the units of measure in *AP-42* (EPA 2002) ; and
- Compared calculation methods to current Emission Inventory Improvement Program (EIIP) methods and updated where calculations did not agree with current methods (EIIP 1999).

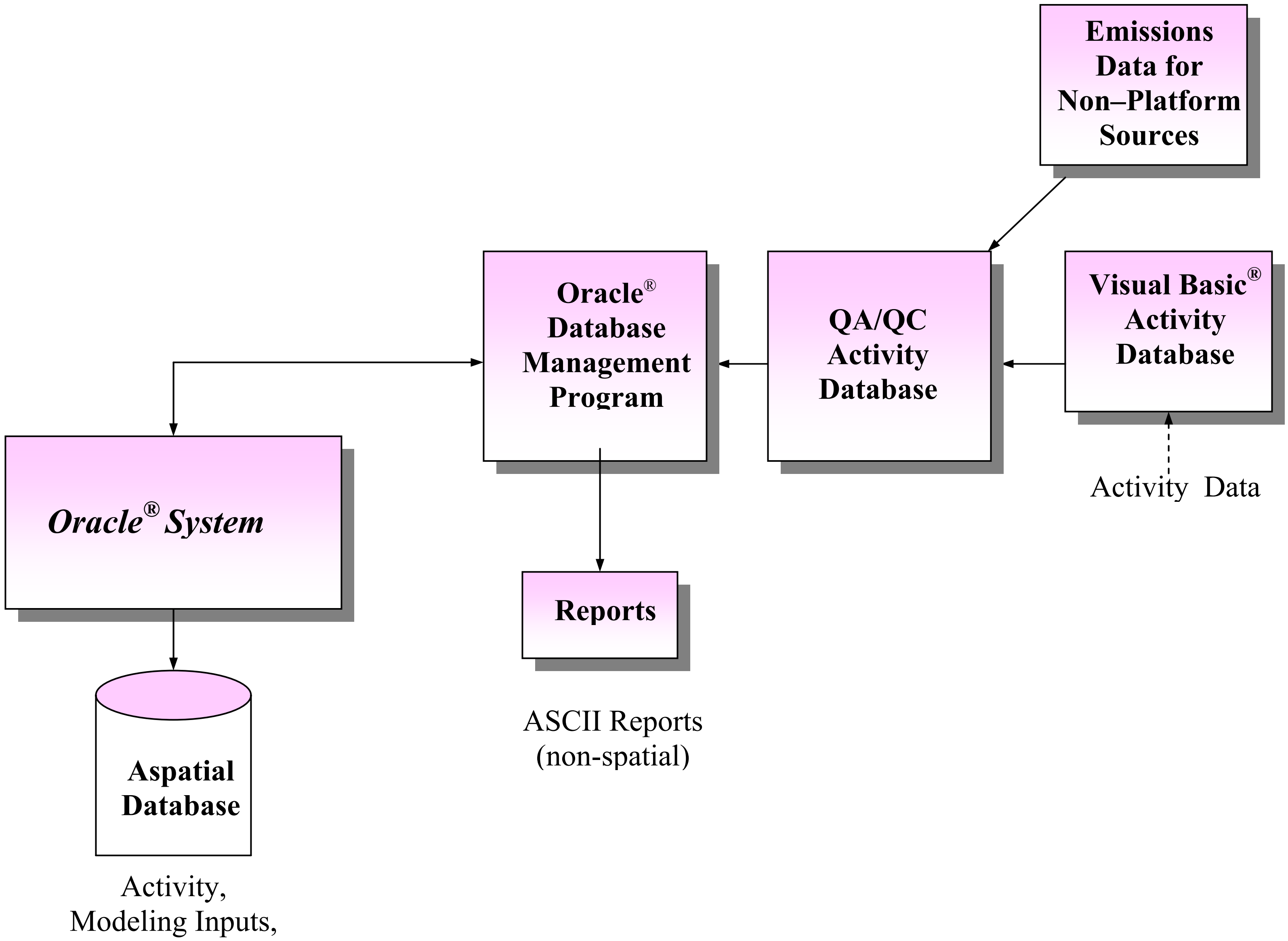

Figure 5-1. Oracle Database Information Flow.

In addition, MMS provided surrogates for values such as fuel sulfur content, fuel heating value, fuel density, and control efficiency. These surrogate values are based on industry averages and/or MMS recommended values. For example, the diesel fuel sulfur content is consistent with MMS' "Spreadsheet for Exploration Plans" (http://www.gomr.mms.gov/homepg/regulate/environ/requirement/html).

Natural gas hydrogen sulfide (H_2S) content	= 3.38 ppmv
Diesel fuel sulfur content	= 0.4 wt%
Natural gas heating value	= 1050 Btu/scf
Diesel fuel heating value	= 19,300 Btu/lb
Diesel fuel density	= 7.1 lb/gal
Gasoline density	= 6.17 lb/gal
Flare efficiency for VOCs	= 98%
Flare efficiency for H_2S	= 95%
Vapor recovery/condensor (VR/C) efficiency for total hydrocarbons (THC) and VOCs	= 80%
Sulfur recovery (SR) + VR/C efficiency for THC and VOCs	= 80%
SR efficiency for THC and VOCs	= 0%

5.3 EMISSION ESTIMATION PROCEDURES

For the most part, the emission estimation procedures presented in this section are unchanged from those in the draft Breton DBMS (Coe et al. 2003). The major revisions reflected here are the addition of new equipment types (mud degassing, pneumatic pumps, and pressure/level controllers) as emission sources, the addition of greenhouse gas emission factors to correspond to the available activity data, updating emission factors with final *AP-42* information, and correcting errors in the draft Breton DBMS.

The following sections present the methods used to calculate criteria pollutant and greenhouse gas emissions from platform sources in the study.

5.3.1 Amine Units

Some platforms produce natural gas containing unacceptable amounts of hydrogen sulfide. While most platform operators pipe the sour gas onshore for sulfur removal, a few remove the sulfur on the platform using the amine process. Various amine solutions are used to absorb H_2S. After the H_2S has been separated out, it is vented, flared, incinerated, or used for feedstock in elemental sulfur production (U.S. DOI, MMS 1995).

Operators were given the option of using the "Model Inputs" tab if requested data were not readily available. CH_4 and VOC emissions are estimated externally using AMINECalc (GTI 2001), and loaded directly into the DBMS. Emissions are adjusted for any control devices that were reported, such as a flare, a vapor recovery system/condenser, or a sulfur recovery unit, and other user-specified control devices. Controlled emissions of VOC are calculated as follows:

$$E_{c,control} = E_{c,unc} \times \sum \frac{100 - Eff_{c,d}}{100\%}$$

where:

$E_{c,control}$ = Controlled VOC emissions (pounds per month)
$E_{c,unc}$ = Uncontrolled VOC emissions (pounds per month)
$Eff_{c,d}$ = Control efficiency of control device d for VOCs (percent)

Devices that are intended to control H_2S emissions, such as sulfur recovery units or flares, will produce emissions of SO_x as a by-product. Thus, if a flare is present, SO_x emissions are calculated as follows (EIIP 1999, Coe et al. 2003):

$$E_{SO_x,control} = E_{H2S}\left(\frac{lb \cdot mol_{H_2S}}{34\ lb_{H_2S}}\right) \times \left(\frac{64\ lb_{SO_x}}{lb \cdot mol_{SO_x}}\right) \times \left(\frac{Eff_{SO_x}}{100}\right)$$

where:

$E_{SOx,\ control}$ = Resulting SO_x emissions (pounds per month)
E_{H_2S} = Uncontrolled emissions of H_2S (pounds per month)
Eff_{SOx} = Flare efficiency (%)

If a sulfur recovery unit is present, SO_x emissions are calculated as follows (EIIP 1999, Coe et al. 2003):

$$E_{SO_x,control} = E_{H_2S}\left(\frac{lb \cdot mol_{H_2S}}{34\ lb_{H_2S}}\right) \times \left(\frac{64\ lb_{SO_x}}{lb \cdot mol_{SO_x}}\right) \times \left(\frac{Eff_{SO_x}}{100}\right) \times \left(\frac{1\ lb \cdot mol_{SO_x}}{3\ lb \cdot mol_S}\right) \times \left(1 - \frac{\%\ RE}{100}\right)$$

where:

$E_{SOx,\ control}$ = Resulting SO_x emissions (pounds per month)
E_{H_2S} = Uncontrolled emissions of H_2S (pounds per month)
% RE = Recovery efficiency of the sulfur recovery unit (%)

5.3.2 Boilers/Heaters/Burners

Boilers, heaters, and burners provide process heat and steam for many processes such as electricity generation, glycol dehydrator reboilers, and amine reboiler units (EIIP 1999). To calculate uncontrolled emissions for liquid-fueled engines (waste oil or diesel) based on fuel use, $E_{fu,liq}$:

$$E_{fu,liq} = EF_{(lb/10^3\ gal)} \times 10^{-3} \times U_{liq} \div 7.1\ lb/gal$$

To calculate uncontrolled emissions for gas-fueled engines (natural gas, process gas, or waste gas) based on fuel use, $E_{fu,gas}$:

$$E_{fu,gas} = EF_{(lb/MMscf)} \times 10^{-3} \times U_{gas}$$

where:

E = Emissions in pounds per month
EF = Emission factor
U_{liq} = Fuel usage (pounds/month)
U_{gas} = Fuel usage (Mscf/month)

If fuel usage is not provided, it is calculated based on hours operated, max rated or average heat input, and fuel heating value.

The following emission factors are used to estimate emissions. These factors come from *AP-42*, Sections 1.3 and 1.4 (EPA 2002). All boilers are assumed to be wall-fired boilers (no tangential-fired boilers). Emission factors for No. 6 residual oil were used to estimate emissions from waste-oil-fueled units.

Table 5-1. Emission Factors for Liquid-Fueled Units – Diesel where Max Rated Heat Input ≥ 100 MMBtu/hr.

	Emission Factors ($lb/10^3$ gal)		
Pollutant	Uncontrolled	Low NO_x Burner	Flu Gas Recirculation
THC	0.252	0.252	0.252
VOC	0.2	0.2	0.2
SO_x	$162.7 \times S$	$162.7 \times S$	$162.7 \times S$
SO_2	$157 \times S$	$157 \times S$	$157 \times S$
SO_3	$5.7 \times S$	$5.7 \times S$	$5.7 \times S$
NO_x	24	10	10
$PM_{2.5}$	0.25	0.25	0.25
PM_{10}	2.0	2.0	2.0
CO	5	5	5
N_2O	0.11	0.11	0.11
CH_4	0.052	0.052	0.052
CO_2	22,300	22,300	22,300

S = Fuel oil sulfur content (wt%)

Table 5-2. Emission Factors for Liquid-Fueled Units – Diesel where Max Rated Heat Input < 100 MMBtu/hr.

Emission Factors ($lb/10^3$ gal)			
Pollutant	Uncontrolled	Low NO_x Burner	Flu Gas Recirculation
THC	0.252	0.252	0.252
VOC	0.2	0.2	0.2
SO_x	$144 \times S$	$144 \times S$	$144 \times S$
SO_2	$142 \times S$	$142 \times S$	$142 \times S$
SO_3	$2 \times S$	$2 \times S$	$2 \times S$
NO_x	20	20	20
$PM_{2.5}$	0.25	0.25	0.25
PM_{10}	2	2	2
CO	5	5	5
N_2O	0.11	0.11	0.11
CH_4	0.052	0.052	0.052
CO_2	22,300	22,300	22,300

S = Fuel oil sulfur content (wt %)

Table 5-3. Emission Factors for Liquid-Fueled Units – Waste Oil where Max Rated Heat Input ≥ 100 MMBtu/hr.

Emission Factors ($lb/10^3$ gal)			
Pollutant	Uncontrolled	Low NO_x Burner	Flu Gas Recirculation
THC	1.28	1.28	1.28
VOC	0.28	0.28	0.28
SO_x	$162.7 \times S$	$162.7 \times S$	$162.7 \times S$
SO_2	$157 \times S$	$157 \times S$	$157 \times S$
SO_3	$5.7 \times S$	$5.7 \times S$	$5.7 \times S$
NO_x	47	40	40
$PM_{2.5}$	$5.23 \times S + 1.73$	$5.23 \times S + 1.73$	$5.23 \times S + 1.73$
PM_{10}	$9.19 \times S + 3.22$	$9.19 \times S + 3.22$	$9.19 \times S + 3.22$
CO	5	5	5
N_2O	0.11	0.11	0.11
CH_4	1.00	1.00	1.00
CO_2 (high S)[a]	24,400	24,400	24,400

S = Fuel oil sulfur content (wt%)

[a] As opposed to oil that has been desulfurized

Table 5-4. Emission Factors for Liquid-Fueled Units – Waste Oil where Max Rated Heat Input < 100 MMBtu/hr.

	Emission Factors ($lb/10^3$ gal)		
Pollutant	Uncontrolled	Low NO_x Burner	Flu Gas Recirculation
THC	1.28	1.28	1.28
VOC	0.28	0.28	0.28
SO_x	159 × S	159 × S	159 × S
SO_2	157 × S	157 × S	157 × S
SO_3	2 × S	2 × S	2 × S
NO_x	55	55	55
$PM_{2.5}$	0.37 × S + 0.12	0.37 × S + 0.12	0.37 × S + 0.12
PM_{10}	9.19 × S + 3.22	9.19 × S + 3.22	9.19 × S + 3.22
CO	5	5	5
N_2O	0.11	0.11	0.11
CH_4	1.00	1.0	1.0
CO_2 (high S)[a]	24,400	24,400	24,400

S = Fuel oil sulfur content (wt%)

[a] As opposed to oil that has been desulfurized

Table 5-5. Emission Factors for Gas-Fueled Units – Natural Gas or Process Gas where Max Rated Heat Input ≥ 100 MMBtu/hr.

	Emission Factors (lb/MMscf)		
Pollutant	Uncontrolled	Low NO_x Burner	Flu Gas Recirculation
THC	11	11	11
VOC	5.5	5.5	5.5
SO_x	0.6	0.6	0.6
NO_x	280	140	100
PM_{10}**	7.6	7.6	7.6
CO	84	84	84
N_2O	2.2	0.64	0.64
CH_4	2.3	2.3	2.3
CO_2	120,000	120,000	120,000

** = Also represents $PM_{2.5}$

Table 5-6. Emission Factors for Gas-Fueled Units – Natural Gas or Process Gas where Max Rated Heat Input < 100 MMBtu/hr.

Emission Factors (lb/MMscf)			
Pollutant	Uncontrolled	Low NO_x Burner	Flu Gas Recirculation
THC	11	11	11
VOC	5.5	5.5	5.5
SO_x	0.6	0.6	0.6
NO_x	100	50	32
PM_{10}**	7.6	7.6	7.6
CO	84	84	84
N_2O	2.2	0.64	0.64
CH_4	2.3	2.3	2.3
CO_2	120,000	120,000	120,000

** Also represents $PM_{2.5}$

5.3.3 Diesel and Gasoline Engines

Diesel and gasoline engines are used to run generators, pumps, compressors, and well-drilling equipment. Most of the pollutants emitted from these engines are from the exhaust. Evaporative losses are insignificant in diesel engines due to the low volatility of diesel fuels (EPA 2002).

If a user-entered value for total fuel used is available, or if it can be estimated from default values then emissions are estimated based upon fuel use. Otherwise, if operating HP and hours operated are both available, then emissions are estimated based upon power output.

To calculate uncontrolled emissions based on fuel use, E_{fu}:

$$E_{fu} = EF_{(lb/MMBtu)} \times 10^{-6} \times U \times \frac{7.1\,lb}{gal} \times H$$

To calculate uncontrolled emissions based on power output, E_{po}:

$$E_{po} = EF_{(g/hp\text{-}hr)} \times HP \times t \times \frac{lb}{453.6g}$$

where:

E = Emissions in pounds per month
EF = Emission factor (units are shown in parentheses)
U = Fuel usage (gallons/month)
H = Fuel heating value (Btu/lb)

HP = Engine horsepower (hp)
t = Engine operating time (hr/month)

The following emission factors are used to estimate emissions. These factors come from *AP-42*, Sections 3.3 and 3.4 (EPA 2002).

Table 5-7. Emission Factors for Gasoline Engines.

Pollutant	EF_{fu} (lb/MMBtu)	EF_{po} (g/hp-hr)
THC	3.03	9.8
VOC	3.03	9.8
SO_x	0.084	0.268
NO_x	1.63	4.99
PM_{10}**	0.1	0.327
CO	62.7	199
CO_2	154.0	489.9

** Also represents $PM_{2.5}$

Table 5-8. Emission Factors for Diesel Engines where Max HP < 600.

Pollutant	EF_{fu} (lb/MMBtu)	EF_{po} (g/hp-hr)
THC	0.36	1.14
VOC	0.33	1.04
SO_x	$1.01 \times S$	$3.67 \times S$
NO_x	4.41	14.1
PM_{10}**	0.31	1
CO	0.95	3.03
CO_2	164.0	521.6

** Also represents $PM_{2.5}$
S = Fuel oil sulfur content (wt%)

Table 5-9. Emission Factors for Diesel Engines where Max HP ≥ 600.

Pollutant	EF_{fu} (lb/MMBtu)	EF_{po} (g/hp-hr)
THC	0.09	0.32
VOC	0.08	0.29
SO_x	1.01 × S	3.67 × S
NO_x	3.2	10.9
$PM_{2.5}$*	0.056	0.178
PM_{10}	0.057	0.182
CO	0.85	2.5
CH_4	0.008	0.03
CO_2	165.0	526.2

S = Fuel oil sulfur content (wt%)
* <3 µm

If the corresponding field is null, a surrogate fuel consumption rate of 7,000 Btu/hp-hr is applied.

5.3.4 Drilling Rigs

Drilling activities associated with an existing facility or from a jack-up rig adjacent to a platform are included because of their emissions associated with gasoline, diesel, and natural gas fuel usage in engines. Total emissions equal the sum of emissions due to gasoline, diesel, and natural gas fuel usage.

For gasoline fuel use, calculate uncontrolled emissions, E_{gas}, as follows (Coe et al. 2003):

$$E_{gas} = EF_{(lb/MMBtu)} \times 10^{-6} \times U \times \frac{6.17\,\text{lb}}{\text{gal}} \times \frac{20{,}300\,\text{Btu}}{\text{lb}}$$

where:

E = Emissions in pounds per month
EF = Emission factor (units shown in parentheses)
U = Fuel usage (gallons)

For diesel fuel use, calculate uncontrolled emissions, E_{die}, as follows (Coe et al. 2003):

$$E_{die} = EF_{(lb/MMBtu)} \times 10^{-6} \times U \times \frac{7.1\,\text{lb}}{\text{gal}} \times \frac{19{,}300\,\text{Btu}}{\text{lb}}$$

where:

E = Emissions in pounds per month
EF = Emission factor (units shown in parentheses)
U = Fuel usage (gallons)

For natural gas fuel use, calculate uncontrolled emissions, E_{ng}, as follows:

$$E_{ng} = EF_{(lb/MMscf)} \times 10^{-3} \times U$$

where:

E = Emissions in pounds per month
EF = Emission factor (units shown in parentheses)
U = Fuel usage (Mscf)

The following emission factors are used to estimate emissions. These factors come from *AP-42*, Sections 3.2, 3.3 and 3.4 (EPA 2002). Diesel engines are assumed to be ≥ 600 hp. Natural gas engines are assumed to be 4-cycle and evenly distributed between lean and rich burns (by averaging).

Table 5-10. Emission Factors for Gasoline Fuel Use.

Pollutant	EF_{gas} (lb/MMBtu)
THC	3.03
VOC	3.03
SO_x	0.084
NO_x	1.63
PM_{10}**	0.1
CO	62.7
CO_2	154

** Also represents $PM_{2.5}$

Table 5-11. Emission Factors for Diesel Fuel Use.

Pollutant	EF_{die} (lb/MMBtu)
THC	0.09
VOC	0.08
SO_x	1.01 × S
NO_x	3.2
$PM_{2.5}$*	0.056
PM_{10}	0.057
CO	0.85
CO_2	165

S = Fuel oil sulfur content (wt%)
* <3 µm

Table 5-12. Emission Factors for Natural Gas Fuel Use.

Pollutant	EF_{ng} (lb/MMscf)
THC	932.3
VOC	75.3
SO_x	0.6
NO_x	2467.5
PM_{10} **	4.9
CO	2127.3
CH_4	755
CO_2	112,200

** Also represents $PM_{2.5}$

5.3.5 Flares

A flare is a burning stack used to dispose of hydrocarbon vapors. Flares can be used to control emissions from storage tanks, loading operations, glycol dehydration units, vent collection system, and amine units. Flares usually operate continuously; however, some are used only for process upsets (U.S. DOI, MMS 1995).

Flare emissions for total hydrocarbons (THC), VOC, NO_x, PM_{10}, and CO are estimated according to the following equation:

$$E_{flare} = V_{tot} \times H \times EF_{flare} \div 1000$$

where:

E_{flare} = Emissions in pounds per month
V_{tot} = Total volume of gas flared (Mscf) = vol flared (Mscf, excluding upsets) + $\sum$ (upset flare feed rate (Mscf/hr) × hours operated)
H = Flare gas heating value (Btu/scf)
EF_{flare} = Emission factor for flares (lb/MMBtu)

SO_x emissions are estimated using to the following equation:

$$E_{flare,SO_x} = \left(\frac{Eff_F\%}{100\%}\right) \times \frac{10^{-6}}{ppm} \times \frac{m_{SO_2}}{379.4 scf/lb \cdot mol} \times 1000 \times \left(V' \times C_{H_2S} + \sum_{i=1}^{n} F_i \times t_i \times C_{H_2S,i}\right)$$

where:

$E_{flare, SOx}$ = Emissions in pounds per month
$Eff_F\%$ = The combustion efficiency of the flare (percent)
m_{SO2} = Molecular weight of SO_2 = 64 lb/lb·mol
V' = Non-upset volume of gas flared (Mscf)
C_{H_2S} = Non-upset concentration of H_2S in the flare gas (ppm)
F_i = Upset flare feed rate for occurrence i (Mscf/hr)
t_i = Duration of occurrence i (hr)
$C_{H_2S,i}$ = H_2S concentration for upset occurrence i (ppm)

If the user indicates there is a continuous flare pilot, pilot light emissions are estimated as follows:

$$E_{pilot} = P \times D \times EF_{pilot} \div 1000$$

where:

E_{pilot} = Pilot emissions in pounds per month
P = Flare feed rate (Mscf/day)
D = Number of days in month
EF_{pilot} = Emission factor for pilot (lb/MMscf)

The following emission factors are used to estimate emissions. These factors come from *AP-42*, Sections 13.5 and 1.4 (EPA 2002). The VOC emission factor is based on the assumption that the flare composition is 45% C2/C3 and 55% C1 by volume (Coe et al. 2003).

Table 5-13. Emission Factors for Flares.[a]

Pollutant	EF (lb/MMBtu)
THC	0.14
VOC	0.052
NO_x	0.068
PM_{10}	0; where flare smoke = none
	0.002; where flare smoke = light
	0.01; where flare smoke = medium
	0.02; where flare smoke = heavy
CO	0.37
CH_4	0.126

[a] Factors are not available for $PM_{2.5}$, N_2O or CO_2.

Table 5-14. Emission Factors for Pilots.

Pollutant	EF (lb/MMscf)
THC	11
VOC	5.5
NO_x	100
PM_{10}	7.6
SO_x	0.6
CO	84
N_2O	2.2
CH_4	2.3
CO_2	120,000

If the corresponding fields are null, the following surrogate values are applied:

Flare Smoke$_{default}$ = None
Pilot Fuel Feed Rate = 2.28 Mscf/day

5.3.6 Fugitives

Fugitive emissions are leaks from sealed surfaces associated with process equipment. Specific fugitive source types include equipment components such as valves, flanges, and connectors (EIIP 1999). Operators were required to delineate the stream type (gas, heavy oil, light oil, or water/oil) and average VOC weight percent of fugitives, and provide an equipment inventory (number of components).

Fugitive THC emissions are estimated according to the following equation:

$$E_{THC} = \sum_{comp}\left(EF_{comp,stream} \times N_{comp}\right) \times D$$

where:

E_{THC} = THC emissions in pounds per month
$EF_{comp,stream}$ = Emission factor unique the type of component and process stream (lb/component-day)
N_{comp} = Count of components of a given type present on the facility. (Note: Null values are treated as zero.)
D = Number of days in month

Fugitive VOC emissions are estimated according to the following equation:

$$E_{VOC} = E_{THC} \times WtFrVOC_{comp,\,stream}$$

where:

E_{VOC} = VOC emissions in pounds per month
E_{THC} = THC emissions in pounds per month
$WtFrVOC_{comp,stream}$ = Weight fraction of VOC unique to the process stream

Fugitive CH_4 emissions are estimated according to the following equation:

$$E_{CH4} = E_{THC} \times WtFrCH_{4\,comp,\,stream}$$

where:

E_{CH4} = CH_4 emissions in pounds per month
E_{THC} = THC emissions in pounds per month
$WtFrCH_{4comp,stream}$ = Weight fraction of CH_4 unique to the process stream

Table 5-15. THC Emission Factors for Oil and Gas Production Operations (lb/component-day).[a]

Component	Gas	Natural Gas Liquid	Heavy Oil (<20 API Gravity)	Light Oil (≥ 20 API Gravity)	Water/Oil	Oil/Water/ Gas[c]
Connector	1.1E-02	1.1E-02	4.0E-04	1.1E-02	5.8E-03	1.1E-02
Flange	2.1E-02	5.8E-03	2.1E-05	5.8E-03	1.5E-04	2.1E-02
Open-end	1.1E-01	7.4E-02	7.4E-02	7.4E-02	1.3E-02	1.1E-01
Other[b]	4.7E-01	4.0E-01	1.7E-03	4.0E-01	7.4E-01	7.4E-01
Pump	1.3E-01	6.9E-01	6.9E-01	6.9E-01	1.3E-03	1.3E-01
Valve	2.4E-01	1.3E-01	4.4E-04	1.3E-01	5.2E-03	2.4E-01

[a] Source: API 1996
[b] Includes compressor seals, diaphragms, drains, dump arms, hatches, instruments, meters, pressure relief valves, polished rods, and vents
[c] Assumed to be equal to either gas or water/oil, whichever is greater

If a component count is not provided, the following surrogate component counts are used (derived from API 1993, average number of offshore platform components, and percentage of total components by type):

Connectors: 9,194
Valves: 1713
Open-Ends: 285
Others: 228

If stream type is not provided, emissions are calculated assuming the stream type is light oil. The default values in Table 5-16 are assigned if the average VOC weight percent field is blank.

Table 5-16. Default Speciation Weight Fractions for Total Hydrocarbon (THC) Emissions By Stream Type.[a]

THC Fraction	Gas	Natural Gas Liquid	Light Oil (≥ 20 API Gravity)	Heavy Oil (<20 API Gravity)	Water/Oil[b]	Oil/Water/ Gas
Methane	0.945	0.612	0.612	0.942	0.612	0.612
VOC	0.0137	0.296	0.296	0.030	0.296	0.296

[a] Source: API 1996
[b] Water/oil refers to water streams in oil service with a water content greater than 50% from the point of origin to the point where the water content reaches 99%. For water streams with a water content greater than 99%, the emission rate is considered negligible

5.3.7 Glycol Dehydrators

Glycol dehydrators remove excess water from natural gas streams to prevent the formation of hydrates and corrosion in the pipeline (EIIP 1999). Surrogate VOC glycol dehydrator still column vent emission estimates were calculated based on regression equations from GRI-GLYCalc version 4 (GTI 2000) computer program runs for varying combinations of wet gas pressure and wet gas temperature. Surrogate glycol dehydrator flash tank vent emissions were also calculated based on regression equations from GRI-GLYCalc version 4 computer program runs for varying combinations of flash tank pressure and flash tank temperature. Table 5-17 presents the surrogate gas analysis used in the runs.

The VOC emission rate in pounds per hour is directly proportional to the volume of gas dehydrated if all other variables are held constant. Thus, emission factors from the GRI-GLYCalc runs were developed to express VOC emissions in pounds per hour per million standard cubic feet per day gas (lbs/hr-MMSCFD) processed. For still column vents, VOC emission factors were developed for over 60 combinations of wet gas pressure and temperature. The emission factors range from 0.0126 lb VOC/hr-MMSCFD at a pressure of 1200 psig and temperature of 50° F, to 0.3357 lb VOC/hr-MMSCFD at a pressure of 600 psig and temperature of 130°F.

For glycol dehydrator flash tanks, VOC emission factors were developed for over 120 combinations of wet gas pressure and temperature, and flash tank pressure and temperature. The lowest emission factor is 0.03457 lb VOC/hr-MMSCFD at a wet gas pressure of 1100 psig and temperature of 70°F, and flash tank pressure of 100 psig and temperature of 75°F. The highest emission factor is 0.09282 lb VOC/hr-MMSCFD at a wet gas pressure of 800 psig and temperature of 90°F, and flash tank pressure of 50 psig and temperature of 125°F.

The following assumptions were used to estimate emissions:

- The wet gas is saturated;
- The volume of dry gas was constant at 10 MMSCFD;
- The dry gas water content is 7 lbs water per MMSCF gas;
- The triethylene glycol (TEG) circulation rate is 3 gallons/lb water removed;
- A gas injection pump is used to recirculate the TEG;
- If a flash tank is present, the flash tank is vented to the atmosphere; and
- No stripping gas used.

Table 5-17. Surrogate Gas Analysis for GLYCalc Runs.

Component	Mole Percent (%)
H_2S	0.000
Nitrogen	0.100
Carbon Dioxide	0.800
Methane	94.500
Ethane	3.330
Propane	0.750
n-Butane	0.150
Iso-Butane	0.150
N-Pentane	0.050
Iso-Pentane	0.050
Iso-Hexanes	0.077
N-Hexane	0.018
Benzene	0.004
Toluene	0.003
Ethylbenzene	0.000
Xylenes	0.001
Trimethylpentane	0.003
Heptanes	0.008
Octanes	0.006
Nonanes	0.000
Decanes +	0.000

5.3.8 Loading Operations

Emissions due to loading operations are generated by the displacement of the vapor space in the receiving cargo hold by liquid product. Loading losses are due to: 1—liquids displacing vapors already residing in the cargo tank, and 2—vapors generated by the liquid being loaded into the cargo tank (EIIP 1999, Boyer and Brodnax 1996). The calculations below assume that ships arrive in uncleaned, ballasted condition and that the previously carried loads were crude oil.

For marine loading of crude petroleum and gasoline, *AP-42* recommends the following equation to calculate THC emissions due to loading of fresh cargo:

$$E_{THC} = \left(0.46 + 1.84 \times (0.44 \times P_{VA} - 0.42) \times \frac{mG}{T_b}\right) \times Q \times \frac{42.0\ \text{gal}}{\text{bbl}} \times 10^{-3}$$

where:

E_{THC}	=	THC emissions (pounds per month)
P_{VA}	=	True vapor pressure of the loaded liquid (psia) = $\exp[A - (B/T_{LA})]$
m	=	Average molecular weight of vapors (lb/lb-mol)
G	=	Vapor growth factor = 1.02
T_b	=	Liquid bulk temperature (°R)
Q	=	The amount transferred (bbl)
A	=	Empirical constant = $12.82 - 0.9672 \times \ln(\text{Reid VP})$
B	=	Empirical constant = $7261 - 1216 \times \ln(\text{Reid VP})$
T_{LA}	=	Daily average liquid surface temperature (°R) = $0.44 \times T_{aa} + (0.56 \times T_b) + (0.0079 \times a \times I)$
T_{aa}	=	Daily average ambient temperature (°R)
a	=	Tank paint solar absorptance
I	=	Daily solar insulation factor ($Btu/ft^2 \cdot day$) = 1437 $Btu/ft^2 \cdot day$[A]

Table 5-18. Daily Average Ambient Temperature, T_{aa}.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°F	63	64	67	71	77	81	84	84	82	76	71	66
°R	523	524	527	531	537	541	544	544	542	536	531	526

Source: National Climate Data Center (ftp://ftp.ncdc.noaa.gov/pub/datasets/coadsdata/), Comprehensive Ocean-Atmosphere Data Set (COADS). Average monthly temperatures for the period 1980-1992 for Marsden Square 81, 10° Box 241, 2° Box 5537

Table 5-19. Tank Paint Solar Absorptance, a.

	Solar Absorptance by Paint Color and Condition	
	Paint Condition	
Paint Color	Good	Poor
Aluminum/Specular	0.39	0.49
Aluminum/Diffuse	0.6	0.68
Grey/Light	0.54	0.63
Grey/Medium	0.68	0.74
Red/Primer	0.89	0.91
White	0.17	0.34

VOC emissions (E_{VOC}, in pounds) are calculated as a percent of THC emissions:

$$E_{VOC} = \text{TankVaporWeightPercentVOC}/100 \times E_{THC}$$

[A] Annual average for New Orleans

The following surrogates are assigned or estimated if the corresponding fields are null:

Reid Vapor Pressure$_{default}$ = 5
$T_{b,default} = T_{aa} + 6 \times a - 1$
Tank Bulk Liquid Temp$_{default}$ = T_{aa}
Tank VOC Molecular Weight$_{default}$ = 50
Tank Vapor Weight Percent VOC$_{default}$ = 85

5.3.9 Losses from Flashing

Flash gas is a natural gas that is liberated when an oil stream undergoes a pressure drop. Flash gas is associated with high, intermediate, and low pressure separators, heater treaters, surge tanks, accumulators, and fixed roof atmospheric storage tanks. Flash gas emissions are only estimated for gas that is vented to the atmosphere or burned in a flare. No emissions are associated with flash gas that is routed back into the system (e.g., sales gas).

If a pressure drop occurs between vessels, flash gas emissions are estimated using the Vasquez-Beggs correlation equations to estimate tank vapors in standard cubic feet per barrel of oil produced. Operators were asked to report the following parameters for each part of the process:

- API gravity of stored oil;
- Operating pressure (psig) of each vessel and immediately upstream (i.e., separator, heater treater, surge tank, storage tank);
- Operating temperature (°F) of each vessel and immediately upstream;
- Actual throughput of oil for each vessel;
- Disposition of flash gas from each vessel – routed to system (e.g., sales pipeline, gas-lift), vented to atmosphere, or burned in flare; and
- SCF of flash gas per bbl of oil throughput (optional).

Flashing losses of THC, in pounds, are calculated according to the following equation:

$$L_f = GOR \times Throughput \times GD$$

where:

L_f	=	THC emissions in pounds per month
GOR	=	Gas-to-oil ratio (scf/bbl) – see discussion below if not provided by operator
Throughput	=	The actual throughput volume for each vessel for the survey period
GD	=	Tank vent hydrocarbon gas density (lb/ft^3) = tank mol weight of gas ÷ 379.4

Gas-to-oil ratio, GOR:

$$GOR = C_1 \times OP^{C_2} \times CSG \times \exp\left(\frac{C_3 \times \text{API gravity}}{\text{Vessel temp} + 460}\right)$$

where:

C_1 = Vasquez-Beggs constant = $\begin{cases} 0.0178; \text{if API gravity} > 30 \\ 0.0362; \text{otherwise} \end{cases}$

OP = Vessel operating pressure (psia)

C_2 = Vasquez-Beggs constant = $\begin{cases} 1.187; \text{if API gravity} > 30 \\ 1.0937; \text{otherwise} \end{cases}$

CSG = Corrected specific gravity of gas (see below)

C_3 = Vasquez-Beggs constant = $\begin{cases} 23.931; \text{if API gravity} > 30 \\ 25.724; \text{otherwise} \end{cases}$

Emissions of CO_2, CH_4, and VOC are estimated using speciation profiles from API publication no. 4638:

$$L_{f,VOC} = L_{f,THC} \times 0.04$$
$$L_{f,CO2} = L_{f,THC} \times 0.02$$
$$L_{f,CH4} = L_{f,THC} \times 0.88$$

If the corresponding field is null, a default API gravity of 37 is applied. A default tank molecular gas weight of 24.994 lbs/lb·mole is also assumed as an industry average.

The following surrogate values are used for the corrected specific gravity of gas (CSG):

API Gravity	Gas Specific Gravity (at 100 psig)
>30	0.93
<30	1.08

5.3.10 Mud Degassing

Hydrocarbon emissions from mud degassing occur when gas that has seeped into the well bore and dissolved or become entrained in the drilling mud is separated from the mud and vented to the atmosphere (EIIP 1999). To estimate mud degassing emissions, operators were asked to provide:

- Number of days that drilling operations occurred; and
- Type of drilling mud used (water-based, synthetic, oil-based).

Emissions were calculated using the equation:

$$E_{THC} = EF_{THC} \times D_{drill}$$

where:

E_{THC} = THC emissions (pounds per month)

EF_{THC} = THC emission factor (lbs/day)

D_{drill} = Number of days in the month that drilling occurred

For water-based and oil-based muds, hydrocarbon emissions are estimated using emission factors provided in the 1977 EPA report: *Atmospheric Emissions from Offshore Oil and Gas Development and Production:*

Water-based muds: 881.84 lbs THC/day
Oil-based muds: 198.41 lbs THC/day
Synthetic based muds: 198.41 lbs THC day

For synthetic-based muds, no information is available on air emission rates. Synthetic-based muds are used as substitutes for oil-based muds, and may occasionally be used to replace water-based muds. Synthetic muds perform like oil-based muds, but with lower environmental impact and faster biodegradability (EPA 2000). No information was found, however, on a possible reduction in THC emissions. Because most emissions are associated with the release of entrained hydrocarbons, and EPA estimates no change in the amount of waste cuttings between synthetic- and oil-based muds (EPA 2000), the oil-based mud THC emission factor is used for synthetic-based muds as well.

THC emissions are speciated as follows (EPA 1977):

Component	Percent Composition by Volume (%)
Methane	83.85
Ethane	5.41
Propane	6.12
Butane	3.21
Pentane	1.40

If the type of mud used was specified but the number of days that drilling occurred is left blank, a surrogate for number of drilling days per month, developed from the activity data submitted for all platforms, is applied:

Water-based muds:	16
Oil-based muds:	14
Synthetic-based muds:	13

5.3.11 Natural Gas Engines

Like diesel and gasoline engines, natural gas engines are used to run generators, pumps, compressors, and well-drilling equipment. Most of the pollutants emitted from these engines are from the exhaust (EPA 2002).

If a user-entered value for total fuel used is available, or if it can be estimated from the default values (below), then emissions are estimated based upon fuel use. Otherwise, if operating horsepower and hours operated are both available, then emissions are estimated based upon power output.

Emissions are calculated based on fuel use as:

$$E_{fu} = EF_{(lb/MMBtu)} \times H \times U \times 10^{-3}$$

Emissions are calculated based on power output as:

$$E_{po} = EF_{(g/hp\text{-}hr)} \times HP \times t \times \frac{lb}{453.6g}$$

where:

E	=	Emissions in pounds per month
EF	=	Emission factor (units are shown in parentheses)
H	=	Fuel heating value (Btu/scf)
U	=	Fuel usage (Mscf/month)
HP	=	Engine horsepower (hp)
t	=	Engine operating time (hr/month)

Tables 5-20 through 5-23 present the emission factors used to estimate natural gas engine emissions. These factors come from *AP-42*, Section 3.2 (EPA 2002).

Table 5-20. Emission Factors for Natural Gas Engines where Engine Stroke Cycle = 2-Cycle and Engine Burn Type = Lean.

Pollutant	EF_{fu} (lb/MMBtu)	EF_{po} (g/hp-hr)
THC	1.64	5.6
VOC	0.12	0.41
SO_2	5.88×10^{-4}	2×10^{-3}
NO_x (<90% load)	1.94	6.6
PM_{10}**	3.84×10^{-2}	0.13
CO (<90% load)	0.353	1.2
CH_4	1.45	4.9
CO_2	110	374.2

** Also represents $PM_{2.5}$

Table 5-21. Emission Factors for Natural Gas Engines where Engine Stroke Cycle = 4-Cycle and Engine Burn Type = Lean.

Pollutant	EF_{fu} (lb/MMBtu)	EF_{po} (g/hp-hr)
THC	1.47	5.00
VOC	0.12	0.41
SO_2	5.88×10^{-4}	2.00×10^{-3}
NO_x (<90% load)	0.85	2.89
PM_{10} **	7.71×10^{-5}	2.6×10^{-4}
CO (<90% load)	0.56	1.9
CH_4	1.25	4.25
CO_2	110	374.2

** Also represents $PM_{2.5}$

Table 5-22. Emission Factors for Natural Gas Engines where Engine Stroke Cycle = 4-Cycle and Engine Burn Type = Rich.

Pollutant	EF_{fu} (lb/MMBtu)	EF_{po} (g/hp-hr)
THC	0.36	1.25
VOC	0.03	0.1
SO_2	5.88×10^{-4}	2.00×10^{-3}
NO_x (<90% load	2.27	7.72
PM_{10} **	9.5×10^{-3}	0.03
CO (<90 % load)	3.51	11.94
CH_4	0.23	0.78
CO_2	110	374.22

**Also represents $PM_{2.5}$

Table 5-23. Emission Factors for Natural Gas Engines where Engine Burn Type = Clean.

Pollutant	EF_{fu} (lb/MMBtu)	EF_{po} (g/hp-hr)
THC	1.47	5.00
VOC	0.12	0.41
SO_2	5.88×10^{-4}	2.00×10^{-3}
NO_x	0.59	2.00
PM_{10} **	7.71×10^{-5}	2.6×10^{-4}
CO	0.88	3.00
CH_4	1.25	4.25
CO_2	110	374.22

**Also represents $PM_{2.5}$

If the corresponding field is null, a fuel consumption rate of 7,000 Btu/hp-hr is applied.

5.3.12 Natural Gas Turbines

A gas turbine is an internal combustion engine that operates with rotary rather than reciprocating motion. Turbines are primarily used to power compressors rather than generate electricity (Boyer and Brodnax 1996). A turbine's operating load has a considerable effect on the resulting emission levels. With reduced loads, there are lower thermal efficiencies and more incomplete combustion (EPA 2002).

If a user-entered value for total fuel used is available, then emissions are estimated based upon fuel use. Otherwise, if operating horsepower and hours operated are both available, then emissions are estimated based upon power output.

To calculate emissions based on fuel use:

$$E_{fu} = EF_{(lb/MMBtu)} \times 10^{-3} \times H \times U$$

To calculate emissions based on power output:

$$E_{po} = EF_{(lb/MMBtu)} \times 10^{-6} \times FU \times HP \times t$$

where:

E	=	Emissions in pounds per month
EF	=	Emission factor (units are shown in parentheses)
H	=	Fuel heating value (Btu/scf)
U	=	Fuel usage (Mscf/month)
FU	=	Average fuel usage (Btu/hp-hr)
HP	=	Turbine horsepower (hp)
t	=	Turbine operating time (hr/month)

The following emission factors are used to estimate emissions. These factors come from *AP-42* Section 3.1(EPA 2002).

Table 5-24. Emission Factors for Natural Gas Turbines.

Pollutant	EF (lb/MMBtu)
THC	1.1×10^{-2}
VOC	2.1×10^{-3}
SO_x*	$0.94 \times S$
NO_x	0.32
PM_{10}**	6.6×10^{-3}
CO	8.2×10^{-2}
N_2O	0.003
CH_4	8.6×10^{-3}
CO_2	110

* S= $(C_{H2S}) \times (1.78 \times 10^{-4})$, %S. C_{H2S} = ppm_v H_2S in fuel. If not available, EF is 3.47×10^{-3} lb/MMBtu

** Also represents $PM_{2.5}$

If the corresponding field is null, a fuel consumption rate of 10,000 Btu/hp-hr is applied.

5.3.13 Pneumatic Pumps

A readily-available supply of compressed natural gas is used to power gas actuated pumps. There is no combustion of the gas because the energy is derived from the gas pressure. These pumps include reciprocating pumps such as diaphragm, plunger, and piston pumps. Most gas actuated pumps vent directly to the atmosphere (Boyer and Brodnax 1996).

Operators were asked to provide the following information for pumps that are in natural gas service:

- Manufacturer and model;
- Amount of natural gas consumed in SCF/hr (optional);
- Hours of operation in the reporting period; and
- Whether it is vented to a manifold, a flare, or the atmosphere.

CO_2, CH_4, THC, and VOC emissions (in pounds) for pneumatic pumps are developed using equation 10.4-3, from Chapter 10, "Preferred and Alternative Methods for Estimating Air Emissions from Oil and Gas Field Production and Processing Operations" (EIIP 1999):

$$E = t \times FU \times (\text{mole weight of gas, lbs/lb-mole}) \times (1 \text{ lb-mole}/379.4 \text{ SCF})$$

where:

E = Emissions in pounds per month
t = Operating time (hr/month)
FU = Fuel usage rate (SCF/hr)

Mole weight of gas = mole percent of constituent/100 × mole weight of constituent/gas MW

To determine the mole percent of each constituent (CH_4, CO_2, THC, and VOC), operators were asked to provide the sales gas composition for their structure. Table 5-25 presents the default gas composition if not provided. Table 5-25 also presents the mole weight for each gas constituent.

If the fuel usage rate is not provided, an average value for each make and model is assigned based on reported manufacturer data, or an average surrogate based on the manufacturer is applied.

Table 5-25. Default Sales Gas Composition.

Component	Default Mol%	Mole Weight (lb/lb-mole)
CO_2	0.80	44.010
CH_4	94.50	16.043
C_2	3.33	30.070
C_3	0.75	44.097
i-C_4	0.15	58.124
n-C_4	0.15	58.124
i-C_5	0.05	72.150
n-C_5	0.05	72.150
C_6	0.099	86.177
C_7	0.011	100.272
C_8+	0.007	114.231

5.3.14 Pressure/Level Controllers

Devices that control both pressure and liquid levels on vessels and flow lines are used extensively in production operations. The units are designed to open or close a valve when a preset pressure or liquid level is reached. The valves are automatically actuated by bleeding compressed gas from a diaphragm or piston. The gas is vented to the atmosphere in the process. Most production facilities use natural gas to actuate the controllers. The amount of gas vented is dependent on several factors, including the manufacturer and application (Boyer and Brodnax 1996).

Operators were asked to provide the following information for controllers that are in natural gas service:

- Service type (pressure control vs. level control);
- Manufacturer and model;
- Amount of natural gas consumed in SCF/hr (optional); and
- Hours of operation in the reporting period.

Similar to pneumatic pumps, CO_2, CH_4, THC, and VOC emissions estimates (in pounds) for pressure and level controllers are developed using the following equation (EIIP 1999):

$$E = \text{No. of units} \times t \times FU \times (\text{mole weight of gas, lbs/lb-mole}) \times (1\ \text{lb-mole}/379.4\ \text{SCF})$$

where:

E = Emissions in pounds per month
t = Operating time (hr/month)
FU = Fuel usage rate (SCF/hr)

Mole weight of gas = mole percent of constituent/100 × mole weight of constituent/gas MW

To determine the mole percent of each constituent (CH_4, CO_2, THC, and VOC), operators were asked to provide the sales gas composition for their structure. Table 5-25 presents the default gas composition if not provided. Table 5-25 also presents the mole weight for each gas constituent.

If the fuel usage rate is not provided, an average value for each make and model is assigned based on reported manufacturer data, or an average surrogate based on the manufacturer and service type is applied.

5.3.15 Storage Tanks

VOC and THC may be lost from storage tanks as a result of flashing, working, and standing losses. This discussion only addresses working and standing losses (L_w and L_s). Flashing losses are estimated separately.

Standing losses result from the expulsion of vapors due to vapor expansion and contraction resulting from temperature and barometric pressure changes. Working losses result from filling and emptying operations (Boyer and Brodnax 1996). These calculations assume that all tanks are fixed roof tanks.

Standing losses of THC in pounds are calculated according to the following equation:

$$L_{s,\,THC} = D \times V_V \times W_V \times K_E \times K_S$$

where:

L_s = Standing losses (lbs/month)
D = Number of days in the month
V_V = Tank vapor space volume (ft^3)
W_V = Stock vapor density (lb/ft^3)
K_E = Calculated vapor space expansion factor (unitless)
K_S = Calculated vented vapor saturation factor (unitless)

Vapor space volume for a horizontal, rectangular tank is calculated as:

$$V_V = \text{Tank Shell Length} \times \text{Tank Shell Width1} \times H_{VO}$$

where:

V_V = Vapor space volume (ft^3)
H_{VO} = Vapor space outage (ft) = Tank Shell Height − Tank Average Liquid Height

Vapor space volume for a vertical, rectangular tank is calculated as:

$$V_V = \text{Tank Shell Width1} \times \text{Tank Shell Width2} \times H_{VO}$$

where:

V_V = Vapor space volume (ft^3)
H_{VO} = Vapor space outage (ft) = Tank Shell Height − Tank Average Liquid Height

Vapor space for a horizontal, cylindrical tank is calculated as:

$$V_v = \frac{\pi \times \text{Tank Shell Diam} \times \text{Tank Shell Length} \times H_{VO}}{4 \times 0.785}$$

where:

V_V = Vapor space volume (ft^3)
H_{VO} = Vapor space outage (ft) = 0.5 × Tank Shell Diameter

Vapor space for a vertical, cylindrical tank is calculated as:

$$V_V = \frac{\pi}{4} \times \text{Tank Shell Diam}^2 \times H_{VO}$$

where:

V_V = Vapor space volume (ft^3)
H_{VO} = Vapor space outage (ft) =

$$\begin{cases} \text{Tank Shell Hgt-Tank Avg Liquid Hgt} + \tfrac{1}{3}\text{Tank Roof Hgt}; \text{if Tank Roof Type} = \text{"cone" or "peaked"} \\ \text{Tank Shell Hgt-Tank Avg Liquid Hgt} + \text{Tank Roof Hgt}\left[\tfrac{1}{2} + \tfrac{1}{6}\left(\frac{\text{Tank Roof Hgt}}{\text{Tank Shell Diam}}\right)^2\right]; \text{if Tank Roof Type} = \text{"dome"} \\ \text{TankShell Hgt-TankAvgLiquidHgt; if Tank Roof Type = "Flat"} \end{cases}$$

Stock vapor density is calculated as:

$$W_v = (\text{Tank VOC Molecular Weight} \times P_{VA}) \div (10.731 \times T_{LA})$$

where:

W_V = Stock vapor density (lb/ft^3)
P_{VA} = True vapor pressure (psia) = $\exp[A - (B/T_{LA})]$
A = Empirical constant = 12.82 − 0.9672 × ln(ReidVP)
B = Empirical constant = 7261 − 1216 × ln(ReidVP)
T_{LA} = Daily average liquid surface temperature (°R) = $0.44 \times T_{aa} + (0.56 \times T_b) + (0.0079 \times a \times I)$
T_{aa} = Daily average ambient temperature (°R)
a = Tank paint solar absorptance

T_b = Liquid bulk temperature (°R)
I = Daily solar insulation factor (Btu/ft^2·day) = 1437 Btu/ft^2·day[A]

Table 5-26. Daily Average Ambient Temperature, T_{aa}.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°F	63	64	67	71	77	81	84	84	82	76	71	66
°R	523	524	527	531	537	541	544	544	542	536	531	526

Source: National Climate Data Center (ftp://ftp.ncdc.noaa.gov/pub/datasets/coadsdata/), ComprehensiveOcean-Atmosphere Data Set (COADS). Average monthly temperatures for the period 1980-1992 for Marsden Square 81, 10° Box 241, 2° Box 5537

Table 5-27. Tank Paint Solar Absorptance, a.

Paint Color	Solar Absorptance by Paint Condition Good	Poor
Aluminum/Specular	0.39	0.49
Aluminum/Diffuse	0.6	0.68
Grey/Light	0.54	0.63
Grey/Medium	0.68	0.74
Red/Primer	0.89	0.91
White	0.17	0.34

The vapor space expansion factor is calculated as:

$$K_E = (T_v/T_{LA}) + (P_v - P_b)/(P_a - P_{va})$$

where:

K_E = Vapor space expansion factor
T_v = Daily vapor temperature range (°R) = 0.72 × T_a+ 0.028 × a × I
T_{LA}= Daily average liquid surface temperature (°R)
P_v = Daily pressure range (psia)= 0.50 × B × P_{va} × T_v/T_{LA}^2
P_b = Breather vent pressure setting range (psig) = Breather vent pressure – breather vent vacuum
P_a = Atmospheric pressure (psia)
P_{va} = Vapor pressure at daily average liquid surface temperature (psia)

The vented vapor saturation factor is calculated as:

$$K_S = 1/(1 + 0.053 \times P_{VA} \times H_{VO})$$

[A] Annual average for New Orleans

where:

K_S = Vented vapor saturation factor
P_{VA} = Vapor pressure at daily average liquid surface temperature (psia)
H_{VO} = Vapor space outage (ft)

Working losses of THC in pounds are calculated according to the following equation:

$$L_{w,\,THC} = 0.0010 \times \text{Tank VOC Mol Weight} \times P_{VA} \times \text{Throughput} \times K_P \times K_N$$

where:

L_w = Working losses
P_{VA} = Vapor pressure at daily average liquid surface temperature (psia)
K_P = Working loss product factor (unitless) = 0.75
K_N = Working loss turnover factor (unitless) = $\begin{cases} 1; \text{for } N \le 36 \\ \frac{180+N}{6N}; \text{for } N > 36 \end{cases}$
N = Number of turnovers per month = 5.614 × throughput/V_{LX}

V_{LX} = Tank maximum liquid volume (ft^3)

Tank maximum liquid volume for a horizontal, rectangular tank is calculated as:

$$V_{LX} = \text{Tank Shell Length} \times \text{Tank Shell Width1} \times \text{Tank Shell Height}$$

Tank maximum liquid volume for a vertical, rectangular tank is calculated as:

$$V_{LX} = \text{Tank Shell Width1} \times \text{Tank Shell Width2} \times \text{Tank Shell Height}$$

Tank maximum liquid volume for a horizontal, cylindrical tank is calculated as:

$$V_{LX} = \frac{\pi}{4} \times \text{Tank Shell Diam}^2 \times \text{Tank Shell Length}$$

Tank maximum liquid volume for a vertical, cylindrical tank is calculated as:

$$V_{LX} = \frac{\pi}{4} \times \text{Tank Shell Diam}^2 \times \text{Tank Shell Hgt}$$

where:

V_{LX} = Tank maximum liquid volume (ft^3)

The following surrogates are assigned or estimated if the corresponding fields are null:

Product type = Crude oil
Paint Color = Grey
Condition = Good
Roof type = Fixed
Roof Shape = Cone
API $Gravity_{default}$ = 37
Reid $VP_{default} = -1.699 + 0.179 \times$ API Gravity (or 5, if no other information is available)
$T_{b,default} = T_{aa} + 6 \times a - 1$ (or 530º R, if no other information is available)
Breather Vent $Pressure_{default}$ = 0.03
Breather Vent $Vacuum_{default}$ = –0.03
Tank Bulk $LiqT_{default} = T_{aa}$
Tank VOC Mol $Weight_{default}$ = 50
Tank Vapor Weight Percen*t* $VOC_{default}$ = 85
Mole $Fraction_{default}$ = 0.9
Tank Avg Liquid $Hgt_{default} = 0.5 \times$ Tank Shell Hgt
Flare $Efficiency_{default}$ = 98

5.3.16 Vents

Production facilities often discharge natural gas to the atmosphere via vents. The discharges can be due to routine or emergency releases. Vents receive exhaust streams from miscellaneous sources, as well as manifold exhaust streams from other equipment on the same platform such as amine units, glycol dehydrators, loading operations, and storage tanks. Emissions from vents are calculated based on the volume of gas vented from miscellaneous equipment (less the volume from the manifold equipment, which are reported with the other equipment) and the chemical composition of the gas.

Vent emissions of VOC are estimated using the following equation:

$$E_{vent,\,VOC} = C_{VOC} \times \frac{10^{-6}}{ppm} \times \frac{m_{VOC}}{379.4 scf/lb \cdot mol} \times 1000 \times \left(V' + \sum_{i=1}^{n} F_i \times t_i \right)$$

where:

$E_{vent,\,VOC}$	=	VOC emissions in pounds per month
C_{VOC}	=	Concentration of VOC in the vent gas (ppmv)
m_{VOC}	=	Molecular weight of VOC (lb/lb·mol)
V'	=	Non-upset volume of gas vented from miscellaneous sources (Mscf)

F_i = Upset vent feed rate for occurrence i (Mscf/hr)
t_i = Duration of occurrence i

Vent emissions of H_2S are estimated using the following equation:

$$E_{vent,H_2S} = \frac{10^{-6}}{ppm} \times \frac{m_{H2S}}{379.4 scf/lb \cdot mol} \times 1000 \times \left(V' \times C_{H2S} + \sum_{i=1}^{n} F_i \times t_i \times C_{H_2S,i} \right)$$

where:

$E_{vent, H2S}$ = H_2S emissions in pounds
C_{H2S} = Concentration of H_2S in the vent gas (ppmv)
m_{H2S} = Molecular weight of H_2S = 34 lb/lb mol
$C_{H2S,I}$ = H_2S concentration of upset occurrence i
V' = Non-upset volume of gas vented from miscellaneous sources (Mscf)
F_i = Upset vent feed rate for occurrence i (Mscf/hr)
t_i = Duration of occurrence i

Vent emissions of CH_4 are estimated using the following equation:

$$E_{vent,CH4} = C_{CH4} \times \frac{10^{-6}}{ppm} \times \frac{m_{CH4}}{379.4 scf/lb \cdot mol} \times 1000 \times \left(V' + \sum_{i=1}^{n} F_i \times t_i \right)$$

where:

$E_{vent, CH4}$ = CH_4 emissions in pounds
C_{CH4} = Concentration of CH_4 in the vent gas (ppmv)
M_{CH4} = Molecular weight of CH_4 = 16 lb/lb • mol
$C_{H2S,I}$ = H_2S concentration of upset occurrence i
V' = Non-upset volume of gas vented from miscellaneous sources (Mscf)
F_i = Upset vent feed rate for occurrence i (Mscf/hr)
t_i = Duration of occurrence i

If a flare is used:

$$Event_{controlled} = Event \times \frac{Eff_{FLARE}}{100\%}$$

The following surrogates are assigned or estimated if the corresponding fields are null:

VOC concentration = 12,700 ppmv (=1.27 mol %)
H_2S concentration = 3.38 ppmv
CH_4 concentration = 945,000 ppmv (=94.5 mol %)

6. NON-PLATFORM SOURCE CATEGORIES

In addition to compiling activity data from platform operators, ERG compiled activity data for OCS as well as non-OCS non-platform sources in the Gulf of Mexico, and developed emission estimates for each source category. Non-platform sources include:

- Biogenic/Geogenic Sources;
- Commercial Marine Vessels;
- Drill Ships;
- Fishing Vessels;
- Helicopters;
- The Louisiana Offshore Oil Platform (LOOP);
- Military Vessels;
- Pipelaying Vessels;
- Platform Construction and Removal;
- Survey Vessels; and
- Vessel Lightering.

The appendices to this report contain documentation for the non-platform sources, activity data, emission factors, and emission estimates developed in this study. As discussed in Appendix M, the resulting emission estimates have also been spatially allocated to MMS lease blocks.

The accuracy of the non-platform emission estimates is dependent on the accuracy of the activity data and the emission factors used. Although activity data used in this study were specific and reasonably accurate for the 2000 base year, some of the activity data are based on adjustments made to activity data that were presented in the 1995 MMS study (U.S. DOI, MMS 1995), which may have been derived from a 1992 Survey of Offshore Operators undertaken by the Offshore Operators Committee. In addition, the marine diesel emission factors are based on typical horsepower and load factors obtained from the 1995 report. These values are considered averages, and actual emissions from specific vessels may differ significantly. Limitations of the non-platform inventory and recommended improvements are discussed in Section 8 and in the appendices.

7. DEVELOPMENT OF THE DIURNAL EMISSION CURVES

7.1 INTRODUCTION

Diurnal emission curves allow inventory emission estimates for a given category to be temporally allocated, across a 24-hour time period, on a 1-hour basis. Hour-by-hour emission estimates of this nature are required in order to run advanced photochemical simulation models such as the Urban Airshed Model. State agencies and the EPA may run such models, inclusive of Gulf of Mexico offshore sources, to address ozone and regional haze issues.

Source operations (and in turn their emissions) are, by their nature, inherently continuous and reasonably uniform or intermittent and non-uniform. For example, production processes are typically continuous (24 hours/day) and consistent because companies want to maximize the utilization of resources and obtain as much return on their investment as possible. Fluctuating operational levels are not consistent with these missions.

Other source types that are not directly production-driven may only operate to fulfill a specific need and may have an operation that is limited by other physical conditions (e.g., is only done in daylight). Meteorological conditions, for example, may also affect a source's daily temporal profile (e.g., higher temperatures at mid day could mean higher emissions than at midnight).

ERG developed diurnal emission curves for all sources in this study, platform as well as non-platform. Since the objective of having diurnal profiles is to support photochemical modeling, the temporal profiles presented in this section are for a typical day in August, during the ozone season. Like onshore situations, the Gulf of Mexico offshore source population consists of large stationary point sources, and various mobile and natural source types.

7.2 APPROACH

The Gulfwide study source population consists of point sources, mobile sources, and natural sources. Because it is infeasible to survey every individual piece of equipment in the study area, offshore industry trends in daily operation were developed for a subset of sources within each major category grouping. This information was then applied to the category as a whole.

The temporal profiles presented here were developed for a typical day in the ozone season. In a typical summer day, activity for production platforms, drilling, tanker-shipping, space cooling, drill rig mobilization, and setting of new platforms were expected to be fairly continuous on a 24-hour basis. This would be especially true for the latter two categories, since companies want to maximize such activities during the good summer weather months. Activities such as helicopter traffic and supply boats are not continuous and generally cycle in conjunction with daylight hours.

ERG obtained the temporal profiling data from a number of sources. Activity levels and diurnal variations are best determined through surveys or estimated using engineering judgement by people familiar with the sources. Direct monthly survey data are available for platform equipment: the monthly hours of operation for each piece of equipment were provided by platform operators through GOADS data collection.

For non-platform sources, information was derived from published industry statistics and the 1995 MMS study *Gulf of Mexico Air Quality Study, Final Report* (U.S. DOI, MMS 1995). COMM Engineering provided information on the daily operational patterns and characteristics of the sources based on their permitting experience with offshore oil and gas operations. Lastly, default allocation algorithms and values were obtained from EPA guidance documents dealing with modeling inventories and modeling requirements for the new ozone and PM-2.5 National Ambient Air Quality Standards (NAAQS) (EPA 1991, 1999, 2001). These guidance documents are designed to help inventory preparers determine hourly emissions.

7.3 SOURCE CATEGORY GROUPINGS AND DIURNAL PATTERNS

The following platform operations are estimated to have essentially constant and uniform operation, with no significant variation in emissions throughout a 24-hour ozone season day (Figure 7-1). The assumed uniform operations for the platform sources are based on information provided by COMM Engineering and in the EPA study *Procedures or the Preparation of Emission Inventories for Carbon Monoxide and Precursor's of Ozone* (EPA 2001):

- Amine units;
- Drilling operations;
- Flares;
- Fugitive emissions;
- Glycol dehydrators;
- Losses from flashing;
- Mud degassing;
- Pneumatic pumps;
- Pressure and level controllers; and
- Vents.

The following non-platform operations are also estimated to have essentially constant and uniform operations. For the most part, the assumed uniform operation for these sources is based on information in the 1995 U.S. DOI MMS study:

- Commercial marine vessels;
- LOOP activities;
- Military vessels;
- Oceangoing barges; and
- Survey and exploration vessels.

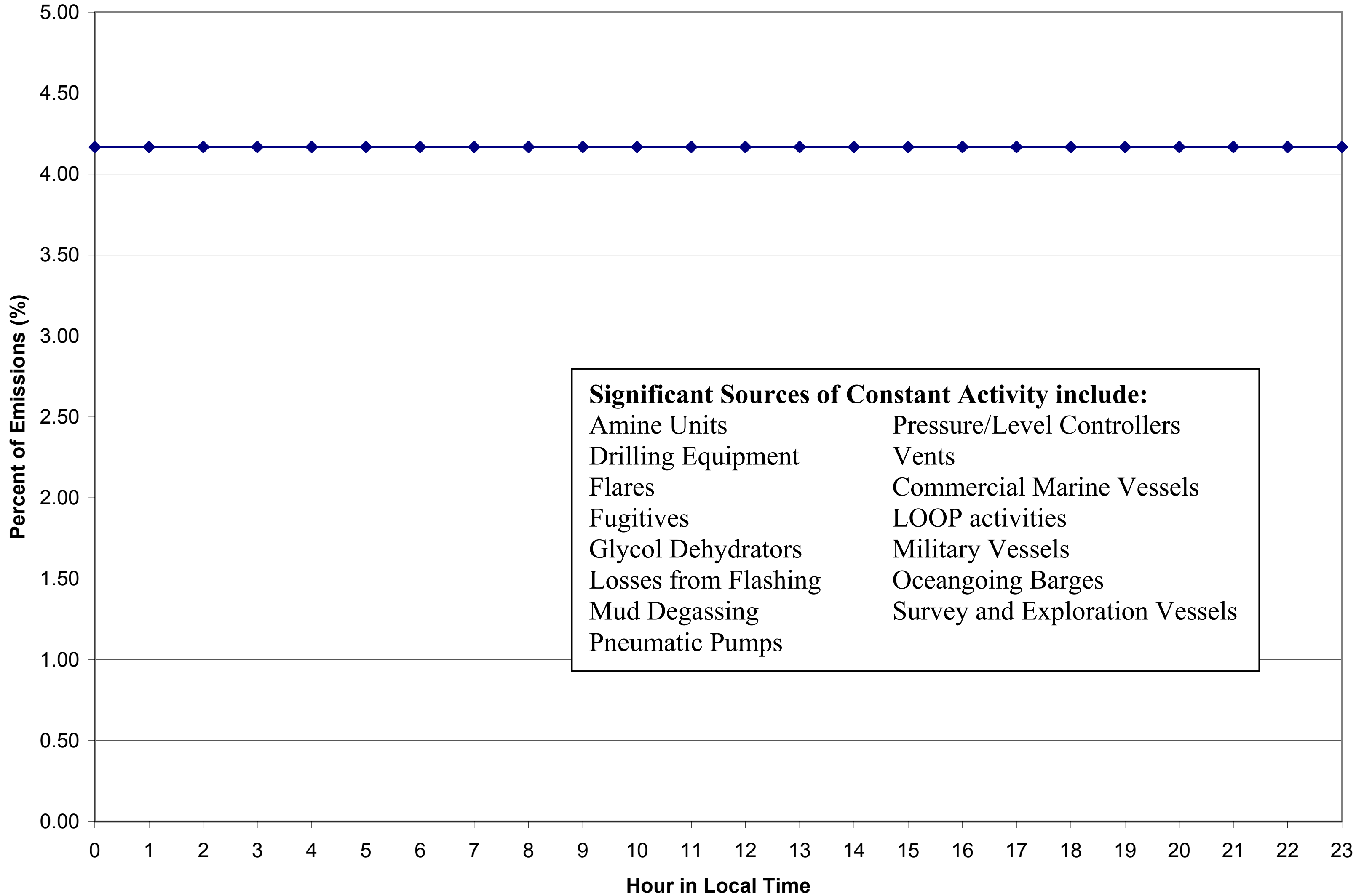

Figure 7-1. Diurnal Emission Curve for Sources of Constant Activity.

Figures 7-2 and 7-3 represent diurnal emission curves for equipment groups that have slight diurnal variation: boilers/heaters/burners, internal combustion engines, and turbines. Diurnal curves are expressed as the percentage of total emissions that occur at each 1-hour interval for each emission source.

Figure 7-4 presents the diurnal curve for source categories whose variation is temperature-driven throughout a 24-hour ozone season day:

- Biogenic Ocean Processes
- Loading Losses
- Oil Seeps
- Storage Tanks

This curve is based on the fluctuation in average air and water temperature (recommended by COMM Engineering) in the GOM (NOAA 2001), as shown in Figure 7-5.

Figure 7-6 presents the diurnal curve for two non-platform operations which average 21 hours of operation per day. This information is based on an offshore operators committee survey, as summarized in the U.S. DOI MMS 1995 report. No further information was found for these operations. The curve assumes no significant activity between the hours of midnight and three a.m. This assumption is simply based on "engineering judgement."

- Helicopters
- Support Vessels - Crew Boats, Supply Boats, Tugs, Barges

Table 7-1 presents the hourly data as a percent of total emissions for each equipment group, and a short explanation as to the data sources used to develop the pattern. Table 7-2 presents the Source Classification Codes (SCCs) used to develop the curves from the EPA (2001) study.

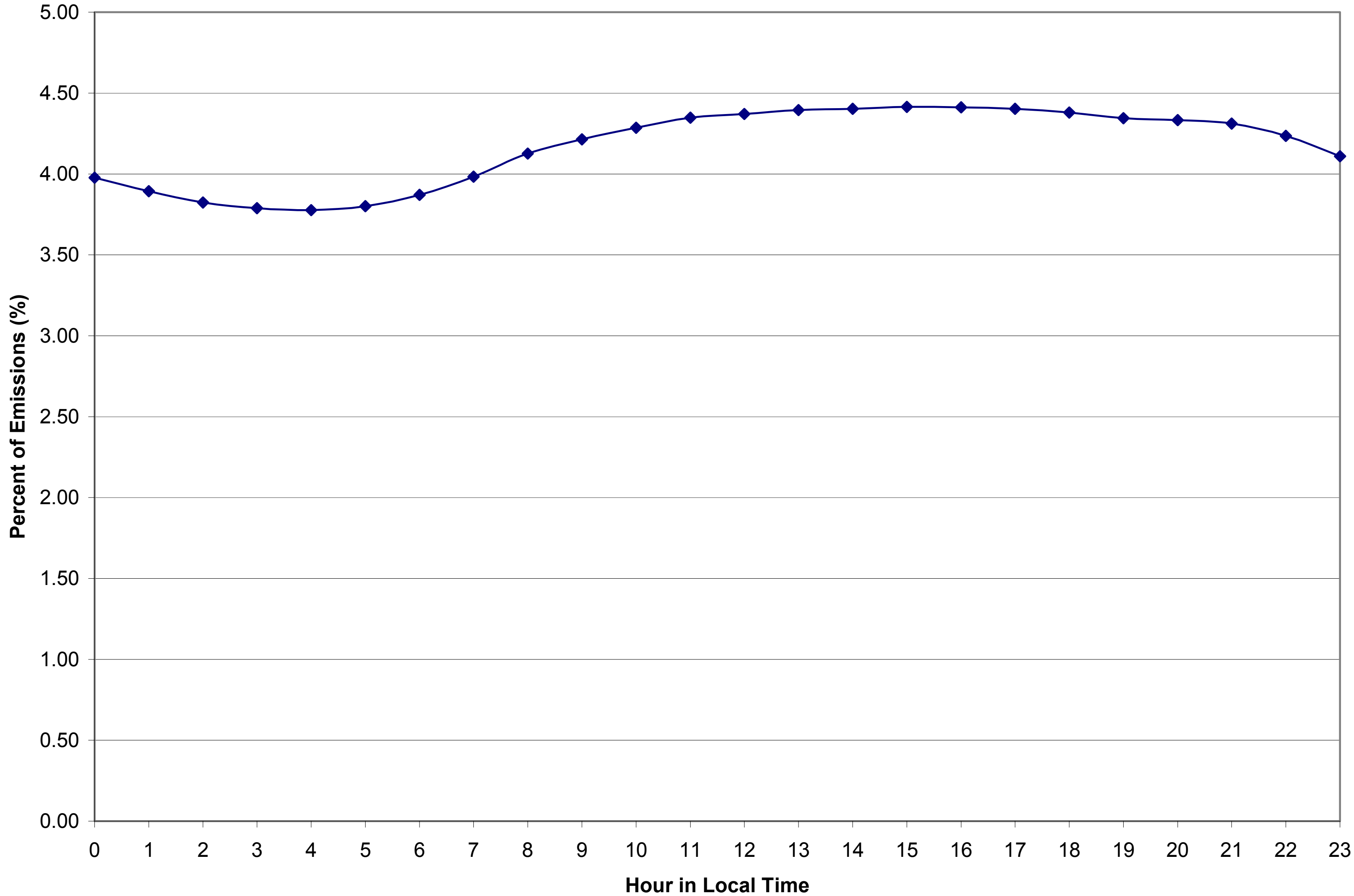

Figure 7-2. Diurnal Emission Curve for Boilers/Heaters/Burners.

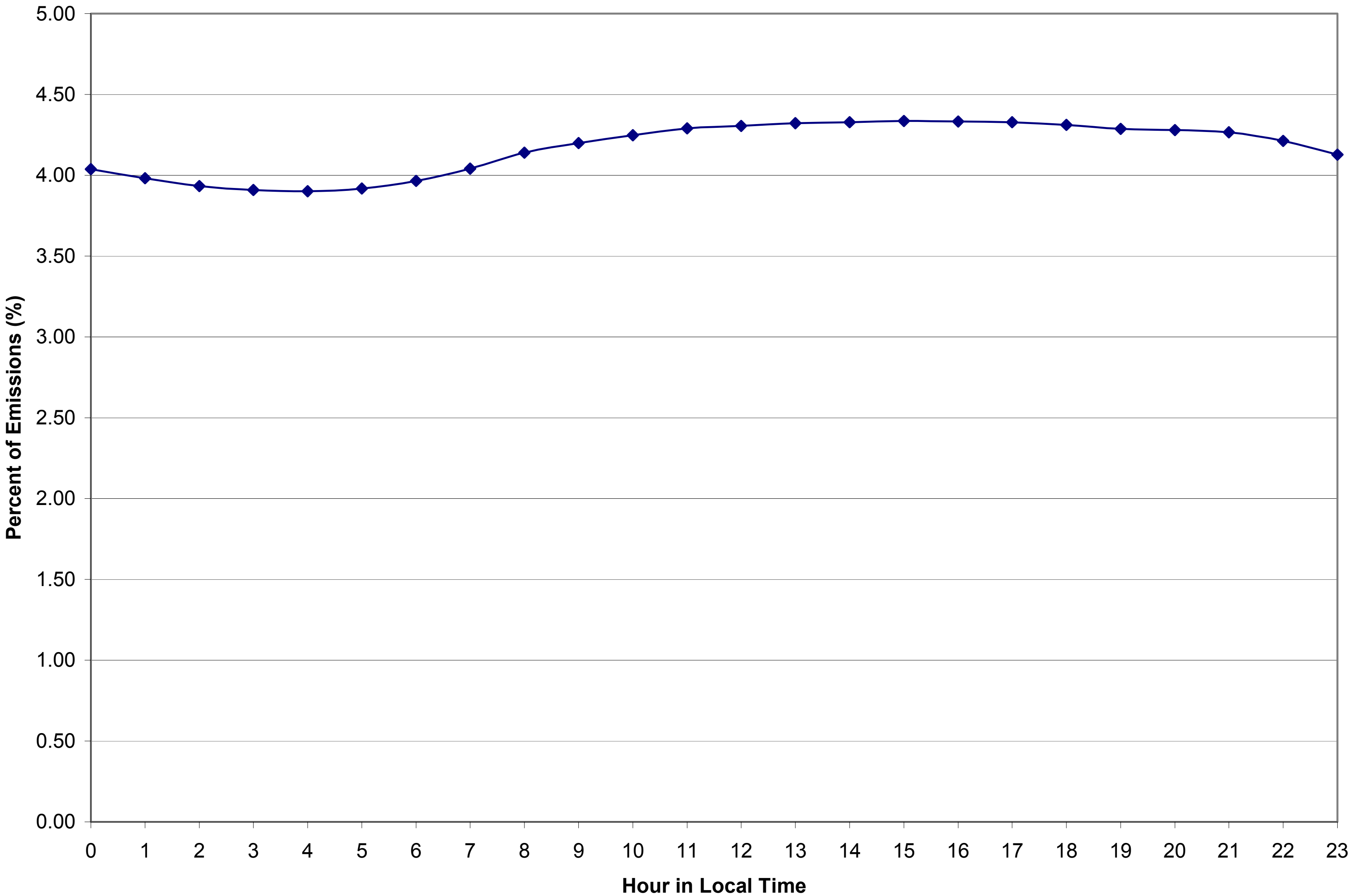

Figure 7-3. Diurnal Emission Curve For Natural Gas Turbines and Internal Combustion Engines.

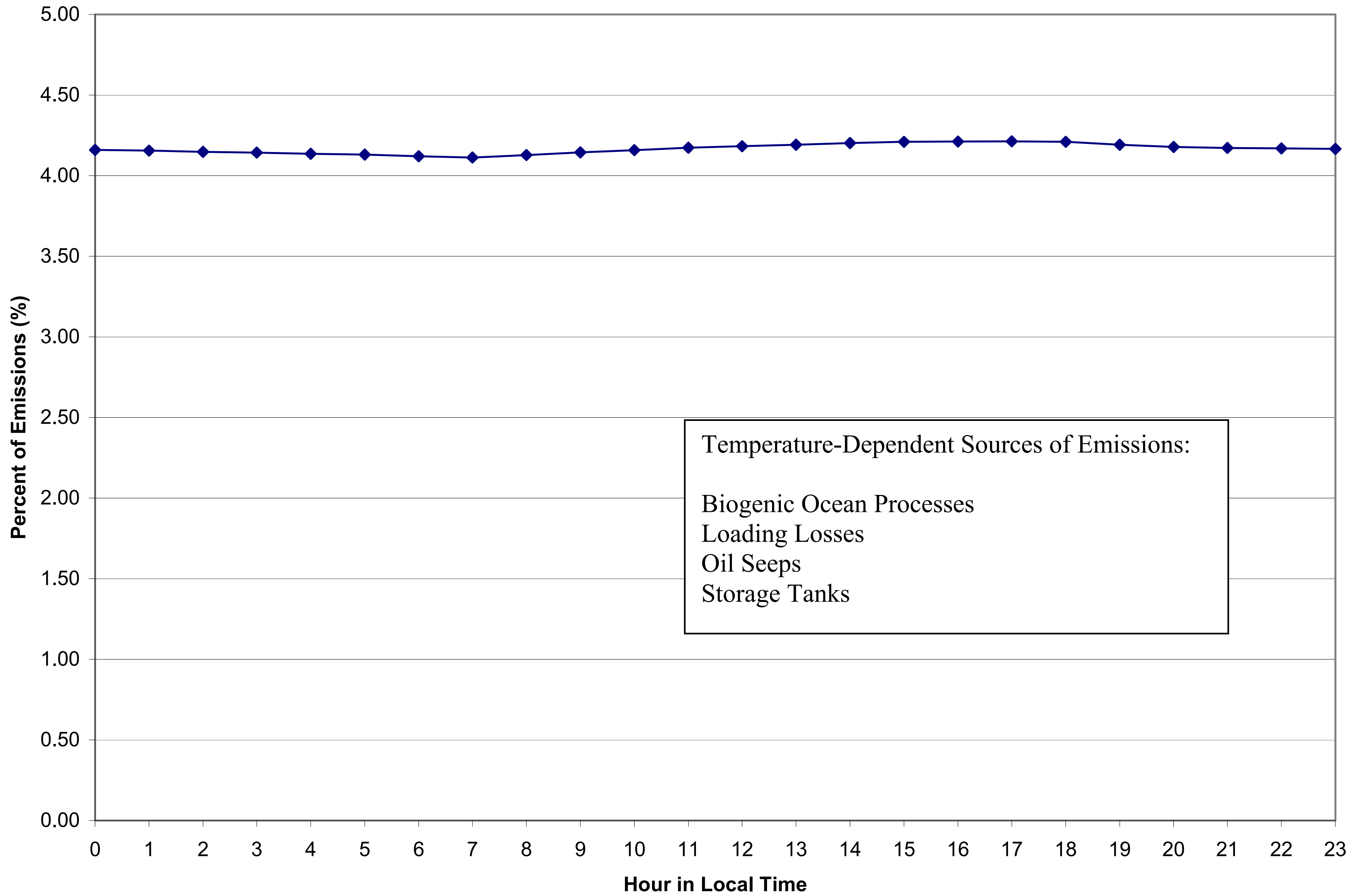

Figure 7-4. Diurnal Emission Curve for Temperature Dependent Activities.

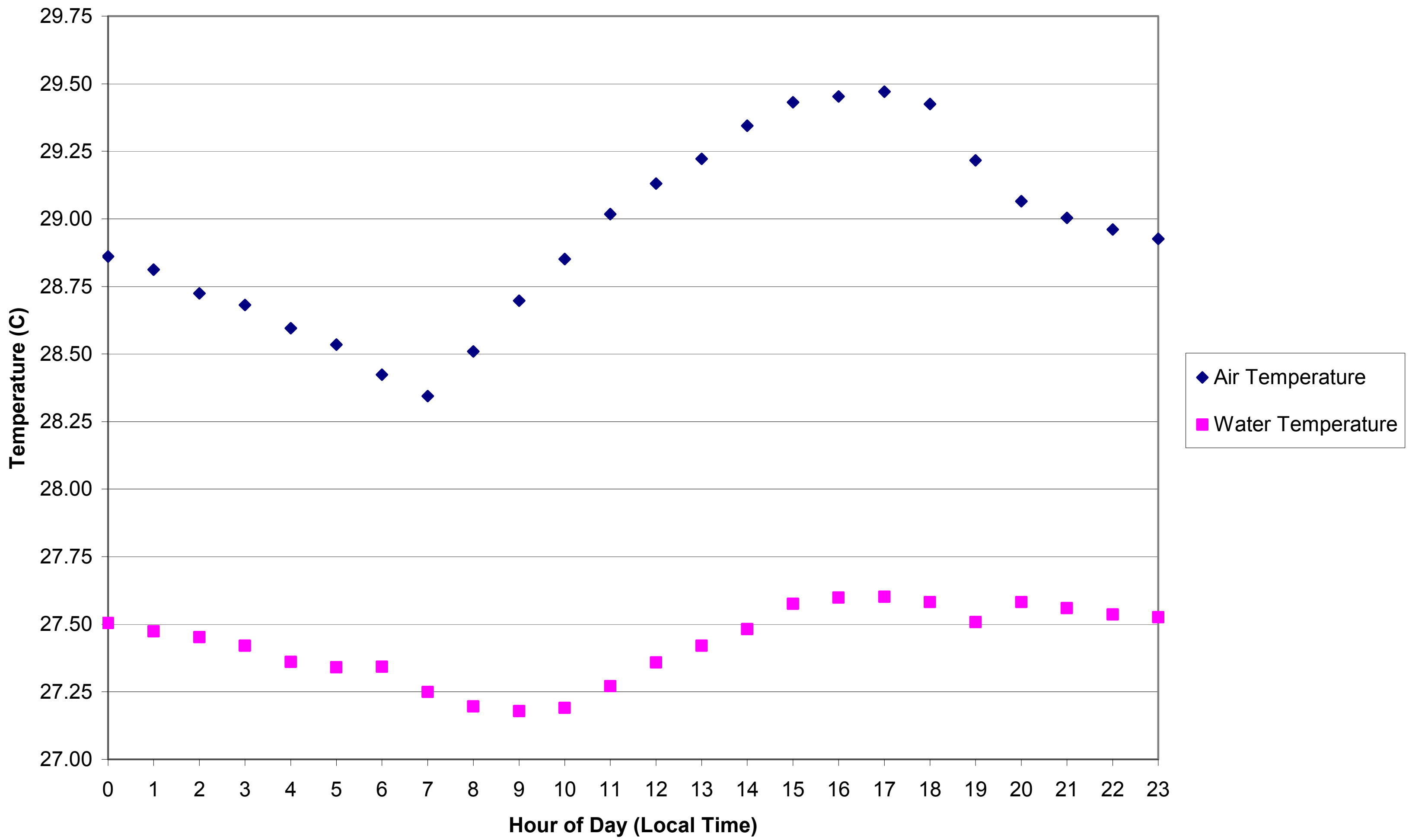

Figure 7-5. Average Air and Water Temperatures for 17 Gulf of Mexico Buoys in August 2000.

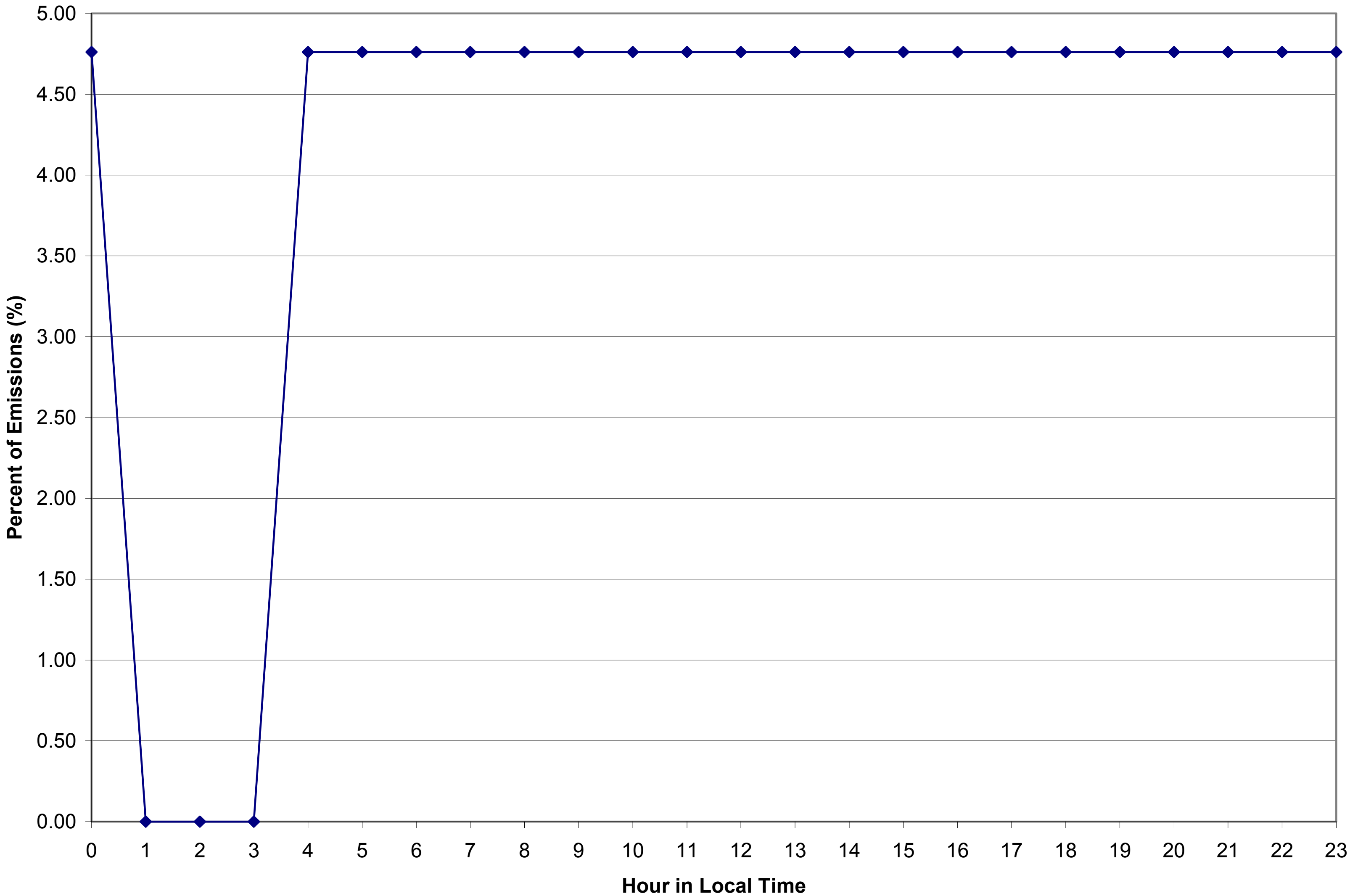

Figure 7-6. Diurnal Emission Curve for Helicopters and Support Vessels.

Table 7-1. Diurnal Emission Percentages for Activity Groups.

	Percentage of Emissions (%)				
Hour (Local Time)	Constant Activity Sources[1]	Boiler/Heater/ Burners[2]	Natural Gas Turbines and ICEs[3]	Temperature-Dependent Sources[4]	Helicopters & Supply Vessels[5]
0	4.17	3.98	4.04	4.16	4.76
1	4.17	3.89	3.98	4.15	0.00
2	4.17	3.82	3.93	4.15	0.00
3	4.17	3.79	3.91	4.14	0.00
4	4.17	3.78	3.90	4.14	4.76
5	4.17	3.80	3.92	4.13	4.76
6	4.17	3.87	3.97	4.12	4.76
7	4.17	3.98	4.04	4.11	4.76
8	4.17	4.13	4.14	4.13	4.76
9	4.17	4.21	4.20	4.14	4.76
10	4.17	4.29	4.25	4.16	4.76
11	4.17	4.35	4.29	4.17	4.76
12	4.17	4.37	4.31	4.18	4.76
13	4.17	4.39	4.32	4.19	4.76
14	4.17	4.40	4.33	4.20	4.76
15	4.17	4.42	4.34	4.21	4.76
16	4.17	4.41	4.33	4.21	4.76
17	4.17	4.40	4.33	4.21	4.76
18	4.17	4.38	4.31	4.21	4.76
19	4.17	4.34	4.29	4.19	4.76
20	4.17	4.33	4.28	4.18	4.76
21	4.17	4.31	4.27	4.17	4.76
22	4.17	4.24	4.21	4.17	4.76
23	4.17	4.11	4.13	4.16	4.76

[1] = Using information provided by MMS (1995), temporal profiles from U.S. EPA (2001), and by engineering judgement, hourly emissions are assumed to be constant and uniform
[2] = Temporal profiles from U.S. EPA (2001) were used to calculate these percentages for boilers, heaters, and burners
[3] = Temporal profiles from U.S. EPA (2001) were used to calculate these percentages for natural gas turbines
[4] = Hourly temperature data were retrieved from NOAA to create a profile for sources dependent upon temperature
[5] = Using information provided by MMS (1995) and by engineering judgement, activities for these sources are assumed to operate continuously from 4 a.m. to midnight

Table 7-2. SCCs of Interest for Platform Operations (Diurnal Patterns).

MMS Group Category	SCC	SCC DESCRIPTION
Amine Units	3-10-002-01	Industrial Processes: Oil and Gas Production - Natural Gas Production, Gas Sweetening: Amine Process
	3-10-003-05	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Gas Sweeting: Amine Process
Boilers/Heaters/ Burners	1-01-006-01	External Combustion Boilers: Electric Generation - Natural Gas, Boilers > 100 Million Btu/hr except Tangential
	1-01-006-02	External Combustion Boilers: Electric Generation - Natural Gas, Boilers < 100 Million Btu/hr except Tangential
	1-01-006-04	External Combustion Boilers: Electric Generation - Natural Gas, Tangentially Fired Units
	1-010-07-01	External Combustion Boilers: Electric Generation - Process Gas, Boilers > 100 Million Btu/hr
	1-010-07-02	External Combustion Boilers: Electric Generation - Process Gas, Boilers < 100 Million Btu/hr
	1-020-06-01	External Combustion Boilers: Industrial - Natural Gas, > 100 Million Btu/hr
	1-020-06-02	External Combustion Boilers: Industrial - Natural Gas, 10-100 Million Btu/hr
	1-020-06-03	External Combustion Boilers: Industrial - Natural Gas, < 10 Million Btu/hr
	1-020-06-04	External Combustion Boilers: Industrial - Natural Gas, Cogeneration
	1-020-07-01	External Combustion Boilers: Industrial - Process Gas, Petroleum Refinery Gas
	1-03-006-01	External Combustion Boilers: Commercial/Institutional - Natural Gas, > 100 Million Btu/hr
	1-030-06-02	External Combustion Boilers: Commercial/Institutional - Natural Gas, 10-100 Million Btu/hr
	1-030-06-03	External Combustion Boilers: Commercial/Institutional - Natural Gas, < 10 Million Btu/hr
	3-100-04-04	Industrial Processes: Oil and Gas Production - Process Heaters, Natural Gas
	3-100-04-05	Industrial Processes: Oil and Gas Production - Process Heaters, Process Gas
	3-100-04-14	Industrial Processes: Oil and Gas Production - Process Heaters, Natural Gas: Steam Generators
	3-100-04-15	Industrial Processes: Oil and Gas Production - Process Heaters, Process Gas: Steam Generators
Drilling	3-100-01-22	Industrial Processes: Oil and Gas Production - Crude Oil Production, Drilling and Well Completion
	3-100-02-22	Industrial Processes: Oil and Gas Production - Natural Gas Production, Drilling and Well Completion
Flares	3-100-01-60	Industrial Processes: Oil and Gas Production - Crude Oil Production, Flares
	3-100-02-05	Industrial Processes: Oil and Gas Production - Natural Gas Production, Flares
	3-100-02-15	Industrial Processes: Oil and Gas Production - Natural Gas Production, Flares Combusting Gases >1000 BTU/scf
	3-100-02-16	Industrial Processes: Oil and Gas Production - Natural Gas Production, Flares Combusting Gases <1000 BTU/scf
Fugitives	3-100-01-01	Industrial Processes: Oil and Gas Production - Crude Oil Production, Complete Well: Fugitive Emissions
	3-100-01-24	Industrial Processes: Oil and Gas Production - Crude Oil Production, Valves: General
	3-100-01-25	Industrial Processes: Oil and Gas Production - Crude Oil Production, Relief Valves
	3-100-01-26	Industrial Processes: Oil and Gas Production - Crude Oil Production, Pump Seals
	3-100-01-27	Industrial Processes: Oil and Gas Production - Crude Oil Production, Ranges and Connections

Table 7-2. SCCs of Interest for Platform Operations (Diurnal Patterns). (Continued)

MMS Group Category	SCC	SCC DESCRIPTION
Fugitive (Continued)	3-100-01-30	Industrial Processes: Oil and Gas Production - Crude Oil Production, Fugitives: Compressor Seals
	3-100-01-31	Industrial Processes: Oil and Gas Production - Crude Oil Production, Fugitives: Drains
	3-100-02-07	Industrial Processes: Oil and Gas Production - Natural Gas Production, Valves: Fugitive Emissions
	3-10-002-02	Industrial Processes: Oil and Gas Production - Natural Gas Production, All Equipment Leak Fugitives (Valves, Flanges, Connections, Seals, Drains)
	3-100-02-23	Industrial Processes: Oil and Gas Production - Natural Gas Production, Relief Valves
	3-100-02-24	Industrial Processes: Oil and Gas Production - Natural Gas Production, Pump Seals
	3-100-02-25	Industrial Processes: Oil and Gas Production - Natural Gas Production, Compressor Seals
	3-100-02-26	Industrial Processes: Oil and Gas Production - Natural Gas Production, Flanges and Connections
	3-100-02-31	Industrial Processes: Oil and Gas Production - Natural Gas Production, Fugitives: Drains
	3-100-03-06	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Process Valves
	3-100-03-07	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Relief Valves
	3-100-03-08	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Open-ended Lines
	3-100-03-09	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Compressor Seals
	3-100-03-10	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Pump Seals
	3-100-03-11	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Flanges and Connections
	3-100-02-27	Industrial Processes: Oil and Gas Production - Natural Gas Production, Glycol Dehydrator Reboiler Still Stack
	3-100-02-28	Industrial Processes: Oil and Gas Production - Natural Gas Production, Glycol Dehydrator Reboiler Burner
	3-100-03-01	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Glycol Dehydrators: Reboiler Still Vent: Triethylene Glycol
	3-100-03-02	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Glycol Dehydrators: Reboiler Burner Stack: Triethylene Glycol
Glycol Dehydrators	3-100-03-03	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Glycol Dehydrators: Phase Separator Vent: Triethylene Glycol
	3-100-03-04	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Glycol Dehydrators: Ethylene Glycol: General
	3-100-03-21	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Glycol Dehydrators: Niagaran Formation (Mich.)
	3-100-03-22	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Glycol Dehydrators: Prairie du Chien Formation (Mich.)
	3-100-03-23	Industrial Processes: Oil and Gas Production - Natural Gas Processing Facilities, Glycol Dehydrators: Antrim Formation (Mich.)
	3-100-01-32	Industrial Processes: Oil and Gas Production - Crude Oil Production, Atmospheric Wash Tank (2nd Stage of Gas-Oil Separation): Flashing Loss

Table 7-2. SCCs of Interest for Platform Operations (Diurnal Patterns). (Continued)

MMS Group Category	SCC	SCC DESCRIPTION
Losses from Flashing	4-04-003-12	Petroleum and Solvent Evaporation: Petroleum Liquids Storage (non-Refinery) – Oil and Gas Field Storage and Working Tanks, Fixed Roof Tank, Crude Oil, working+breathing+flashing losses
	4-04-003-22	Petroleum and Solvent Evaporation: Petroleum Liquids Storage (non-Refinery) – Oil and Gas Field Storage and Working Tanks, External Floating Roof Tank, Crude Oil, working+breathing+flashing
	4-04-003-32	Petroleum and Solvent Evaporation: Petroleum Liquids Storage (non-Refinery) – Oil and Gas Field Storage and Working Tanks, Internal Floating Roof Tank, Crude Oil, working+breathing+flashing
Natural Gas Turbines and ICEs	2-010-02-01	Internal Combustion Engines: Electric Generation - Natural Gas, Turbine
	2-010-02-08	Internal Combustion Engines: Electric Generation - Natural Gas, Turbine: Evaporative Losses (Fuel Delivery System)
	2-010-02-09	Internal Combustion Engines: Electric Generation - Natural Gas, Turbine: Exhaust
	2-02-002-01	Internal Combustion Engines: Industrial - Natural Gas, Turbine
	2-02-002-03	Internal Combustion Engines: Industrial - Natural Gas, Turbine: Cogeneration
	2-02-002-08	Internal Combustion Engines: Industrial - Natural Gas, Turbine: Evaporative Losses (Fuel Delivery System)
	2-02-002-09	Internal Combustion Engines: Industrial - Natural Gas, Turbine: Exhaust
	2-03-002-02	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Turbine
	2-03-002-03	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Turbine: Cogeneration
	2-03-002-04	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Cogeneration
	2-03-002-05	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Reciprocating: Crankcase Blowby
	2-03-002-06	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Reciprocating: Evaporative Losses (Fuel Delivery System)
	2-03-002-07	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Reciprocating: Exhaust
	2-03-002-08	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Turbine: Evaporative Losses (Fuel Delivery System)
	2-03-002-09	Internal Combustion Engines: Commercial/Institutional - Natural Gas, Turbine: Exhaust

8. RESULTS

8.1 SUMMARY OF STUDY APPROACH

MMS' *Gulfwide Emission Inventory Study* required an extensive inventory development effort. The study includes all oil and gas production platforms and non-platform sources in the entire Gulf of Mexico. Pollutants covered in the inventory are the criteria pollutants—CO, SO_x, NO_x, PM_{10}, $PM_{2.5}$, and VOC; as well as greenhouse gases—CO_2, CH_4, and N_2O.

MMS attempted to collect activity data from each and every active offshore oil production platform in the Gulf. Operators were provided with the GOADS Visual Basic activity data collection software for compiling monthly data for calendar year 2000. Nearly 2,900 oil and gas production platforms submitted monthly equipment activity data files. The platform equipment surveyed includes:

- Amine units;
- Boilers/heaters/burners;
- Diesel engines;
- Drilling equipment;
- Flares;
- Flashing losses;
- Fugitive sources;
- Glycol dehydrators;
- Loading operations;
- Mud degassing;
- Natural gas engines;
- Natural gas turbines;
- Pneumatic pumps;
- Pressure/level controllers;
- Storage tanks; and
- Vents.

Non-platform sources covered in the inventory are:

- Biogenic/geogenic sources;
- Commercial fishing;
- Commercial marine vessels;
- Drilling rigs;
- The Louisiana Offshore Oil Platform (LOOP);
- Military vessel operations;
- Pipe laying operations;
- Platform construction and removal vessels;
- Support helicopters;
- Support vessels;

- Survey vessels; and
- Vessel lightering.

Rigorous QA/QC was performed on the activity data collected from platform operators. Tasks were implemented to correct the number of operating hours provided for a given month, fill in missing monthly operating data (if equipment was operational), verify and correct activity values such as fuel heating value, make sure that the equipment shown to be vented included a vent ID and activity record, fill in missing stack parameters with surrogates, and double check exit velocity and fuel usage totals by recalculating the parameters. The monthly activity data collected from the platform operators were then combined with emission factors and algorithms to develop the platform production equipment emission estimates.

Inventory data files were compiled with the oil and gas production platform data, suitable for use in air quality modeling applications. In addition to monthly emission estimates by pollutant and individual piece of equipment, the files include the company, structure, and complex ID, lease number, block and area number, and latitude/longitude. For each piece of equipment, stack parameter information such as outlet height, exit velocity, and exit temperature is also presented.

ERG compiled base year 2000 activity data and developed emission estimates for non-platform sources in the Gulf. For the most part, the emission factors used to calculate the emissions from all of the engines for these sources were obtained from the EPA's Office of Transportation and Air Quality (OTAQ) in Ann Arbor, Michigan. OTAQ published the emission equations along with their Diesel Marine Vessel Rule in 2002. The resulting emission estimates are also disaggregated to MMS lease blocks.

8.2 PRESENTION OF ANNUAL EMISSION ESTIMATES

The platform and non-platform emission estimates developed for criteria pollutants and greenhouse gases are presented in Tables 8-1 through 8-19. For an overview of the results, Table 8-1 summarizes the total platform criteria pollutant emission estimates, Table 8-2 summarizes the total non-platform criteria pollutant emission estimates, and Table 8-3 presents the combined platform and non-platform criteria pollutant estimates. To facilitate more detailed review, Tables 8-4 through 8-9 present platform emission estimates by pollutant. Tables 8-10 through 8-17 present platform emission estimates by type of equipment. The greenhouse emission estimates are provided in Tables 8-18 and 8-19.

8.3 LIMITATIONS

As with the development of any inventory of activity data or emission estimates, the accuracy can vary considerably depending upon the accuracy of the activity data obtained and the emission factors used. The key limitation and source of uncertainty associated with OCS oil/gas production platform inventory effort pertains to the completeness of the platform activity data gathered and used to develop emission estimates. It is difficult to confirm that all affected lessees and operators of federal oil, gas, and sulfur leases in the Gulf of Mexico OCS region provided GOADS files to MMS as required. It is also difficult to track active versus inactive platforms on an annual basis. For example, operators were told to submit records for "satellite" platforms that have no emission sources on them. There may have been no equipment activity data records associated with these platforms, but MMS records show the platform as active in 2000. Platform ownership changes make it difficult to track month-to-month completeness.

At the equipment level, there is no way of knowing how well the operators understood what activity data were being requested. For example, losses from flashing occur at all points where an oil stream undergoes a pressure drop. Operators were asked to determine all sources of flash gas that are vented or flared. Each point of separation/treatment had to be examined as a potential source of flash gas. Flash gas can be vented to the atmosphere or burned in flares from the following equipment: high, intermediate, and low-pressure separators; heater treaters; surge tanks; accumulators; and fixed roof atmospheric storage tanks. It is believed that emissions from flashing are underestimated because operators did not completely report the sources.

In addition, some emission estimates were developed based on the use of surrogates if the actual data needed to estimate emissions were not provided directly. Uncertainty is introduced when the survey respondent lacks an understanding of the data request or incorrectly interprets the data request, and when conflicting survey data are reviewed and adjusted for use in developing emission estimates. Typographical data entry errors also probably occurred in the monthly activity data that were not identified by the equipment survey consistency or data range checks discussed in Section 4 of this report.

This project included the development of two software programs; the GOADS software to gather OCS oil and gas production platform activity data, and the DBMS software to calculate air emissions based on this activity data and current emission factors. In a recent review of the draft GOADS 2000 inventory, a discrepancy was noticed between reported GOADS venting and flaring activity data and the vented and flared gas volumes reported on the Oil and Gas Operations Report (OGOR), Form MMS-4054. Based on an extensive quality control of records for several platforms, the GOADS software used to collect activity data was adjusted to improve flaring and venting volume estimates in the GOADS inventory. The adjustments to the software resulted in considerably more accurate accounting of flaring and venting volumes, and volumes closer to the OGOR values. The emissions from these sources in the GOADS inventory may still be higher than actual values, however. MMS has made several modifications to the GOADS software to reduce these errors in the future. The software has been modified to simplify the data requested each month to only the equipment variables that change monthly. This will reduce data entry volume, processing time, and the likelihood of data entry errors.

The estimates for some non-platform source categories such as support vessels and naval operations were based on adjustments made to activity data that were included in the *Gulf of Mexico Air Quality Study* (GMAQS) (U.S. DOI, MMS 1995). Much of the non-platform activity data used in the 1995 study were derived from a 1992 Survey of Offshore Operators undertaken by the Offshore Operators Committee (OOC). This 1992 report contains useful information, and it would have been helpful if a similar study could have been performed for this 2000 inventory effort.

In addition, most of the non-platform sources are powered by marine diesel engines. In this study, marine diesel emission factors were developed using recent EPA emission equations derived from a large number of "in use" vessel test data. These emission equations require horsepower and operating load factors. Typical horsepower and load factors were obtained from the GMAQS. These values are averages, such that actual emissions from specific vessels may be significantly different. These averages lend uncertainty to the estimates for drill ships and pipelaying operations, among others. It should also be noted that the activity data used to estimate emissions from survey vessels were only for surveys implemented at non-active lease blocks. Survey activity for active lease blocks is considered confidential and not tracked by MMS; therefore actual Gulfwide survey vessel activity will be larger than the activity quantified in this inventory.

8.4 RECOMMENDATIONS

Based on the limitations discussed above, recommendations for future inventory efforts for platform sources in the Gulf of Mexico focus on the data gathering tools used. The uncertainty associated with the flashing, vent, and flare emission estimates is due to the interpretation of the data requested by the operators. Plans are already in place to improve the GOADS software for these equipment types. In addition, an overall improvement will be made to the software to simplify the data requested each month to only the equipment variables that change monthly. This will reduce data entry volume, processing time, and the likelihood of data entry errors.

Improvements in the data collection software, continued operator education and training, use of the MMS web site to post Frequently Asked Questions (FAQs), and increased efforts to identify companies that need to respond to the data request will reduce much of the uncertainty associated with future inventory efforts.

For non-platform sources, the following recommendations are provided to improve the accuracy of the emission estimates or enhance the spatial allocation of the estimates. These suggestions are provided by source category in order of significance relative to total emissions.

- **Implementation of Support Vessels Survey** - Implementation of a survey of marine vessels supporting offshore oil platforms can provide important data that would allow for the development of a more accurate estimate of emissions from these vessels. This support vessel survey could collect detailed information about vessel size, horsepower rating, and typical operating loads, as well as annual and seasonal activity. This information could be used to update the OOC's survey performed in 1992 for the GMAQS. The new survey vessel inventory could be used to develop emission estimates in terms that can be readily applied to state-of-the-art geographic information system (GIS) tools to spatially allocate emissions with greater accuracy.

- **Development of Drill Ship Database** - Currently, MMS collects very specific data on where specific drill ships operate and the length of time they spend at a given site. In the Gulfwide inventory, the average horsepower and load data were used to estimate emissions from these sources. Some vessels may be significantly larger or smaller than these average values, however, such that actual emissions may differ significantly from the estimated emissions. A drill ship database could contain information about vessel size, the number and horsepower of the primary propulsion engine and ancillary engines, and better estimates on typical operating loads. This database could be linked up with MMS's drill ship-specific activity data and available emission factors to provide more accurate emission estimates.

- **Implementation of Pipelaying Survey** – MMS maintains an excellent GIS file of pipelaying construction and maintenance activities which is very useful in assigning emissions to appropriate lease blocks. The emission estimates that have been developed for the Gulfwide inventory for this source category are based on many assumptions that were carried over from the GMAQS, particularly regarding the number of vessels needed for pipeline construction and maintenance and the horsepower rating and typical load of the primary propulsion and ancillary engines. Emission estimates can be improved upon by updating these assumptions through interviews with companies involved in these activities.

- **Platform Construction and Removal Vessels** – The current approach to estimating emissions associated with the construction and removal of offshore oil platforms is based on the number of pilings that a platform has and the ocean depth at the platform. These data are not readily available and the data set developed for this source category in the Gulfwide inventory is not complete. Approximately 20 percent of the data do not include the number of platform pilings; for these cases, a surrogate was developed that is based on the number of floors associated with a given platform. There is also a concern that piling drilling associated with platform construction is not included in the emission estimates. An emission estimation approach needs to be developed to account for drilling associated with platform construction, or to determine if the drilling emissions are already associated with the drill ships category. It is important to insure that these drilling estimates do not double count with emission estimates for the drill ship source category. There is a similar concern of double counting with support vessels that may be involved with the construction or removal of platforms. To resolve these issues it will be necessary to study this source category more fully and meet with staff from companies involved with these activities.

- **Implementation of Survey Vessel Survey** - MMS maintains excellent records of survey vessel activity; the problem is that these records are only required for non-active lease blocks. Survey activities related to active lease blocks are considered confidential information and are not tracked by MMS. It should be pointed out that there are a relatively small number of survey vessels operating in the Gulf. In order to develop an estimate of survey activities associated with active lease blocks, it is necessary to survey the companies that provide geophysical surveying services to estimate annual operating hours (excluding activities in the Eastern Gulf area, state, and international waters) and typical operating loads to develop a Gulfwide estimate for this source category. Survey vessel activity and emissions associated with the non-active lease blocks can be removed from the Gulfwide estimate to approximate emissions in the active lease blocks. These emissions can be applied equally to the active lease blocks based on a surrogate, such as surface area, in order to maintain the confidentiality of these data, while still providing complete emission estimates for this source category.

- **Development of Military Vessel Database** - As noted in this report, obtaining detailed data from the military can sometimes be very difficult. In the current inventory, emission estimates for the Navy are based on conservative estimates of the amount of time vessels operate in the Gulf; actual emissions may be significantly lower than these estimates. Unfortunately, the Navy did not provide any additional information to adjust these estimates to more accurately reflect actual emissions. It is recommended that a database be developed with all of the data required to estimate emissions and spatially and temporally adjust these estimates to represent activity in the Gulf. The database could include assumptions about the current vessel fleet operating in the Gulf, the horsepower of the primary and ancillary engines of each vessel, typical operating loads, and estimates of seasonal and annual hours of operation, as well as information concerning the geographic area where these vessels typically operate. This database could be shared with the Navy and Coast Guard, and they hopefully would update it with their own, more accurate data and submit it to MMS for inclusion in the Gulfwide inventory.

- **Implementation of Support Helicopter Survey** - As with support vessels, implementation of a detailed survey of support helicopters that service offshore oil platforms would allow for better quantification of the types of helicopters currently used, a better estimate of the hours of operation, as well as information to help spatially distribute estimated emissions. The data obtained from such a study should be compiled in a format compatible with GIS data files associated with the current inventory.

- **Incorporation of New Biogenic/Geogenic Data** - Biogenic/geogenic studies continue to be developed, particularly with regard to greenhouse gas emissions. Much of these data are site specific or provided in terms that do not easily convert into typical emission factors. Still, it is important to incorporate the latest emissions data to better quantify these emission sources and evaluate associated emission sinks. Particular attention should be placed on development of spatially allocated emission estimates using the latest GIS tools to more accurately define the location of these significant emission sources. This will probably require evaluating satellite remote sensing data or space shuttle photographs.

8.5 COMPARISON WITH OTHER STUDIES

At the completion of any emissions inventory effort, one final, useful QA/QC check is to compare the inventory results with those from similar inventories. The most applicable inventory to compare the results presented here is the GMAQS (U.S. DOI, MMS 1995). The GMAQS was developed for sources in the OCS and state waters, and included oil and gas production facilities, crew and supply boats and helicopters, recreational and commercial shipping, pipeline vessels, military vessels, inter-coastal barges, and the LOOP.

8.5.1 OCS Oil and Gas Production Platforms

For OCS oil and gas production platforms, survey forms were designed to solicit the data needed to estimate emissions. The resulting platform database had information for 1,855 platforms (U.S. DOI, MMS 1995). The Gulfwide Study discussed in this report included 2,873 platforms, an increase of 55%. For CO, emissions reported in this study increased four-fold, primarily because of natural gas engines. Emission did not show an increase for all pollutants, however. For VOC, emissions in the Gulfwide Study are slightly lower than in the GMAQS. The two studies have a similar number of boiler, diesel and natural gas engine, and natural gas turbine units (irrespective of the increased number of platforms included), but emissions of NO_x and PM are higher in the GMAQS, as shown in Table 8-20. Emissions of SO_x decreased significantly in the Gulfwide Study primarily due to the amine unit estimates.

Table 8-21 presents a summary of emission factors used to estimate fuel combustion emissions in both studies. The higher natural gas engine emission factor accounts at least in part for the increased CO emissions. The primary sources of NO_x and PM in both studies are boilers/heaters/burners, diesel engines, natural gas engines, and natural gas turbines. As noted above, the number of fuel combustion units included in the two studies are similar, even though 55% more platforms reported in the Gulfwide study. Aside from the reported activity data for each equipment type, a review of the emission factors used in each study provides a good indication of why NO_x and PM emissions are lower in the current study. Estimates for both studies were developed based on *AP-42* emission factors (EPA 2002), but the emission factors have been changed for natural gas engines and natural gas turbines. For example, the average NO_x emission factor for natural gas engines is 50% lower than the factor applied in the GMAQS. The contribution of natural gas engines to total NO_x emissions accounts for a large portion of the decrease in emissions compared to the GMAQS. In addition, the PM emission factor is 65% lower for natural gas engines.

The discrepancy in the SO_x estimates, almost entirely because of the amine unit estimates, is not so clearly understood; however, as discussed in Section 5 of this report, the emission estimates in the current study were developed using operator-supplied data and the Gas Technology Institute's AMINECalc program (GTI 2001). The level of confidence in these results is quite high.

8.5.2 Non-Platform Sources

This Gulfwide Study non-platform inventory built upon the GMAQS inventory such that many of the assumptions made in the earlier inventory were used in this study, especially with regard to typical vessel horsepower and operating load, seasonal variation, and hours of operation. However, the Gulfwide Study estimates were based on more recent emission factors, and activity data specific to 2000.

Table 8-22 compares the GMAQS and 2000 Gulfwide Study non-platform emission estimates for individual source categories. In many cases, the difference between the GMAQS estimates and those in the Gulfwide Study are due to the use of different marine diesel emission factors. The GMAQS was based on older EPA *AP-42* emission factors, while the Gulfwide Study estimates were based on the marine diesel emission factors derived from regression analysis performed on recent marine diesel emissions testing data. These new emission factors were recently developed to support the EPA's new marine diesel rule making. The new emission factors tend to be significantly higher for NO_x and CO, and in many cases, though not all, lower for VOC, than those that are reported in the *AP-42* (EPA 2002). The situation for VOCs is further complicated because it is unclear how the hydrocarbon estimates in the GMAQS were converted to represent VOC estimates.

Much of the activity data developed for non-platform sources in the GMAQS were derived from a survey implemented by the OOC. The data collected during the survey is reasonably helpful in quantifying the fleet composition and activity of several hard to quantify emission sources, such as support vessels and helicopters. When better data were not available, the 1992 survey data were adjusted to approximate activity in 2000.

For most of the other source categories it is particularly difficult to discern what activity data were used in the GMAQS, as the results are rarely summarized in a fashion that facilitates comparisons. Emission comparisons between the two studies are discussed below in greater detail for each non-platform source category.

- **Survey Vessels/Drilling Vessels -** In this study, this source category is disaggregated into two categories. The estimates were combined in Table 8-22 to be comparable with the estimates in the GMAQS. The biggest difference between these two studies for this source category concerns the VOC emission estimates. About half of the difference can be accounted for due to the use of different emission factors. For example, the VOC emission factor used in the Gulfwide Study is 37% lower for survey vessels, 13% lower for drill ships, 45% lower for jack-ups, and 17% lower for semisubmersibles than the factors used in the GMAQS. The remainder of the difference is probably due to differences in activity data. Unfortunately, it was not possible to directly compare the data used in the two studies, but it appears that the GMAQS included activities occurring in state waters; these were excluded from the 2000 Gulfwide Study area.

- **Support Vessels -** In both inventories, support vessels included supply vessels, tugs, and barges. The NO_x and CO emissions were significantly higher in the current study, while VOC was significantly lower. The vessel population used in the Gulfwide Study is 17% higher than the vessel population reported in the GMAQS. This adjustment was made to reflect the increase in the number of active oil platforms between 1992 and 2000 and the associated need for additional support vessels. This adjustment accounts for some of the NO_x and CO increase in the 2000 inventory. As noted in the discussion above, recent EPA marine diesel VOC emission factors are lower than the *AP-42* emission factors used in GMAQS. On the other hand, the newer emission factors for NO_x and CO are significantly larger than the factors used in the GMAQS. For example, for supply boats, NO_x emission factors used in the Gulfwide Study are approximately 160% higher and CO emission factors are 85% higher than those used in the GMAQS. It is important to realize that supply boats represent approximately 60% of the support vessel fleet. The remaining difference between the two studies probably is due to the use of different activity data. In the GMAQS, emissions were estimated based on fuel usage as provided by the OOC. For the Gulfwide Study, emissions are estimated based on hours of operation, which used the assumption noted in the GMAQS that the vessels typically operate 21 hours per day. This assumption does not account for periods of time when the support vessels are in port for normal maintenance or due to inclement weather, such that the Gulfwide Study activity may overestimate actual emissions.

- **Support Helicopters -** The support helicopter emission estimates in the Gulfwide Study is significantly higher than the estimates in the GMAQS. The Gulfwide Study estimates are based on more recent helicopter emission factors that tend to be significantly higher than the factors used in the GMAQS. For example, the average VOC emission factor used in the Gulfwide Study is 315% higher; the average NO_x emission factor is 950% higher, and the average CO emission factor is 548% higher than the average factors used in the GMAQS. A more detailed assessment is not possible at this time as the GMAQS documentation did not include information showing how the helicopters in the 1995 activity dataset were matched to the helicopters which had emission factors. Some of the difference between the two studies may also be due to increased helicopter activity between 1992 and 2000. Unfortunately, it is difficult to compare the activity data used in the GMAQS with that used in the Gulfwide Study, as summary information is not provided in the GMAQS report.

- **Pipelaying Vessels -** VOC and CO estimates in the Gulfwide Study tend to be significantly higher than estimates in the GMAQS. As described in the GMAQS report, one of the six vessels used in typical pipelaying activities was a supply vessel, which was already accounted for in the supply vessel source category. Therefore the typical number of vessels used to lay pipe was reduced to avoid double counting. This would account for a decline of approximately 15% of the difference between the two inventories. Most of the remaining difference between the data in the GMAQS and the Gulfwide Study are due to use of different emission factors. For example, the VOC emission factor used in the Gulfwide Study is 73% less than the factor used in the GMAQS. The situation regarding CO emissions is more perplexing, as the emission factor used in the Gulfwide Study is 13% larger than the emission factor used in the GMAQS, while the emission estimate is 34% less. No explanation can be provided without further examination of the activity data used in the GMAQS.

- **LOOP -** Emission estimates for all pollutants are significantly higher in the Gulfwide Study inventory despite the fact that the number of vessels visiting the LOOP in 2000 was 275, which is roughly similar to the number of vessels used in the GMAQS (265).

Approximately 65% of the Gulfwide Study emissions associated with the LOOP occur while the vessel is in hotel mode. This occurs while the vessel is unloading product or at anchorage waiting to unload. The hoteling emission factors used in the GMAQS and the Gulfwide Study inventories are significantly different. For example, in the Gulfwide Study inventory, the emission factor for NO_x was 380% larger, VOC was 1500% larger, and CO was 2400% larger than those used in the GMAQS.

- **Fishing -** Emissions associated with commercial fishing operations are lower in the Gulfwide Study. Much of this may be explained by the fact that the GMAQS 1995 fishing emission estimates included inshore shrimp, oyster, crab, and miscellaneous fin-fishing activities that are not included in the Gulfwide Study, as they occur within state waters. Given the different geographical range of the two studies, it is not surprising that the GMAQS emission totals for this source category are significantly larger than the Gulfwide Study estimates. Shallow water commercial fishing operations use a variety of marine gasoline and diesel engines, while offshore commercial fishing operations primarily use diesel powered vessels. It should be noted that gasoline engines tend to emit significantly more VOC and CO, particularly two-stroke gasoline engines, than marine diesel engines. In developing the Gulfwide Study, it was determined that the majority of recreational fishing occurs within state waters and therefore are not included in the 2000 inventory. The amount of recreational fishing that occurs in federal waters could not be quantified, but it was assumed to be small. The GMAQS did quantify recreational fishing, but the estimates are not included in this comparison in order to get a more accurate source category match between the two inventory efforts.

- **Military Vessels -** A considerable amount of resources were devoted early in this inventory development effort to update the military vessel emission estimates. This was anticipated to be a very challenging task, as military agencies tend not to provide appropriate data to estimate vessel emissions, if they provide any data at all. For this Gulfwide Study inventory, the Coast Guard provided very useful data that supported development of ship-specific emission estimates for the Gulf fleet. In the GMAQS, emission estimates for Coast Guard activities were not included, which accounts for part of the increase in emissions for this source category. Despite repeated attempts to get accurate activity data from the naval fleet operating in the Gulf, the Navy did not provided any data to estimate emissions. The data that were developed in the GMAQS were applied to the latest EPA marine diesel emission factor to get hourly emission factors. As the Navy did not provide activity data, it was assumed that the naval fleet operating in the Gulf operated 8760 hours per year. This is likely an overestimate of Gulf activities, but without assistance from the Navy it was not possible to accurately discern the composition of the fleet and actual hours of operation. Residual-fueled vessel emission estimates are developed using available fuel-based emission factors. The gas turbine emission factors were recently updated in EPA's *AP-42* due to extensive testing associated with the development of EPA's gas turbine regulatory standard. These new gas turbine emission factors are also provided in terms of fuel usage. Note, both the residual-fueled vessels and the gas turbine-powered vessels account for a relatively small portion of the naval fleet and emissions.

- **Commercial Marine Vessels -** All pollutant emissions for commercial marine vessels were significantly lower in the 2000 Gulfwide Study. Some of this can be accounted for by the fact that the GMAQS seems to all commercial marine vessel activity, including those occurring in state waters. This is a particularly significant addition, as state waters include traffic along the inter-coastal waterway and vessel traffic entering and leaving the Mississippi delta. Based on the Army Corps of Engineer's data, traffic within state waters account for over 50% of the total activity in the Gulf. The GMAQS commercial marine vessel activity data may also have included shipping traffic associated with the Eastern Gulf. Table 8-23 provides a comparison of the data with 2000 Gulfwide Study estimates in federal OCS production waters (i.e., Western and Central Gulf areas) and an estimate using the Gulfwide Study methodology for shipping traffic in the Eastern Gulf and state waters. Also included in Table 8-22 are emission estimates developed for oceangoing and coastal vessels obtained from Corbett and Fischbeck (2000). These national estimates were adjusted to approximate Gulf emissions by taking into consideration that 37% of the cargo tonnage is handled in the Gulf as documented in a U.S. Maritime Administration Office of Statistical and Economic Analysis report entitled *U.S. Vessel Calls at U.S. Ports – 2000* (U.S. Maritime Administration 2002). Note the Corbett study used older *AP-42* emission factors, similar to those used in GMAQS.

  Some of the remaining difference can be accounted for due to the emission factors used in the GMAQS and Gulfwide Study. For example, the Gulfwide Study emission factors are approximately 14% less for NO_x, 83% less for VOC, and 23% less for CO, relative to the emission factors used in the GMAQS. These values are very similar to the percent differences noted in Table 8-23.

Table 8-1. Total Platform Emission Estimates for Criteria Pollutants.

Equipment	CO Emissions (tpy)	NO_x Emissions (tpy)	PM_{10} Emissions (tpy)	$PM_{2.5}$ Emissions (tpy)	SO_x Emissions (tpy)	VOC Emissions (tpy)
Amine Units	0	0	0	0	2,100	1
Boilers/heaters/ Burners	511	446	29	29	2	21
Diesel Engines	894	4,043	194	193	143	217
Drilling Equipment	7,759	9,783	176	173	1,197	487
Flares	471	90	2	0	1	8
Fugitives	0	0	0	0	0	29,826
Glycol Dehydrators	0	0	0	0	0	2,572
Loading Losses	0	0	0	0	0	7
Losses From Flashing	0	0	0	0	0	3,625
Mud Degassing	0	0	0	0	0	353
Natural Gas Engines	80,679	56,546	241	241	17	1,542
Natural Gas Turbines	1,830	7,141	147	147	12	47
Pneumatic Pumps	0	0	0	0	0	2,316
Pressure/level Controllers	0	0	0	0	0	990
Storage Tanks	0	0	0	0	0	5,627
Vents	0	0	0	0	0	11,897
Total Emissions (tpy)	92,144	78,049	789	783	3,472	59,536

Table 8-2. Total Non-Platform Emission Estimates for Criteria Pollutants.

Source Category	CO Emissions (tpy)	NO_x Emissions (tpy)	PM_{10} Emissions (tpy)	SO_x Emissions (tpy)	VOC Emissions (tpy)
Drilling Rigs	2,862	27,270	677	4,587	263
Helicopters	6,060	1,438	107	177	2,285
Pipelaying Vessels	1,877	17,887	444	3,009	173
Platform Construction and Removal Vessels	474	3,637	91	620	49
Support Vessels	5,104	37,118	929	6,352	542
Survey Vessels	19	188	5	32	2
Total OCS Oil/Gas Production Sources (tpy)	16,396	87,538	2,253	14,777	3,314
Biogenic/geogenic Sources	0	0	0	0	13,561
Commercial Marine Vessels	1,936	19,487	498	3,545	182
Fishing Vessels	187	1,899	47	318	17
LOOP	2,222	5,106	147	945	1,118
Military Vessels	451	4,592	129	967	41
Vessel Lightering	8,740	18,839	550	3,505	9,525
Total Non-OCS Oil/Gas Production Sources (tpy)	13,536	49,923	1,371	9,280	24,444
Total Non-Platform Emissions (tpy)	29,932	137,461	3,624	24,057	27,758

Table 8-3. Total Platform and Non-Platform Emission Estimates for Criteria Pollutants.

Equipment/ Source Category	CO Emissions (tpy)	NO_x Emissions (tpy)	PM_{10} Emissions (tpy)	SO_x Emissions (tpy)	VOC Emissions (tpy)
Total Platform Emissions	92,144	78,049	789	3,472	59,536
Drilling Rigs	2,862	27,270	677	4,587	263
Helicopters	6,060	1,438	107	177	2,285
Pipelaying Vessels	1,877	17,887	444	3,009	173
Platform Construction and Removal Vessels	474	3,637	91	620	49
Support Vessels	5,104	37,118	929	6,352	542
Survey Vessels	19	188	5	32	2
Total OCS Oil/Gas Production Source Emissions	108,540	165,587	3,042	18,249	62,850
Total Non-OCS Oil/Gas Production Source Emissions	13,536	49,923	1,371	9,280	24,444
Total Emissions (tpy)	122,076	215,510	4,413	27,529	87,294

Table 8-4. Annual CO Emission Estimates for Platform Sources.

Equipment	CO Emissions (tpy)
Natural Gas Engines	80,679
Drilling Equipment	7,759
Natural Gas Turbines	1,830
Diesel Engines	894
Boilers/heaters/burners	511
Flares	471
Total Emissions (tpy)	92,144

Table 8-5. Annual NO_x Emission Estimates for Platform Sources.

Equipment	NO_x Emissions (tpy)
Natural Gas Engines	56,546
Drilling Equipment	9,783
Natural Gas Turbines	7,141
Diesel Engines	4,043
Boilers/heaters/burners	446
Flares	90
Total Emissions (tpy)	78,049

Table 8-6. Annual PM_{10} Emission Estimates for Platform Sources.

Equipment	PM_{10} Emissions (tpy)
Natural Gas Engines	241
Diesel Engines	194
Drilling Equipment	176
Natural Gas Turbines	147
Boilers/heaters/burners	29
Flares	2
Total Emissions (tpy)	789

Table 8-7. Annual $PM_{2.5}$ Emission Estimates for Platform Sources.

Equipment	$PM_{2.5}$ Emissions (tpy)
Natural Gas Engines	241
Diesel Engines	193
Drilling Equipment	173
Natural Gas Turbines	147
Boilers/heaters/burners	29
Total Emissions	783

Table 8-8. Annual SO_x Emission Estimates for Platform Sources.

Equipment	SO_x Emissions (tpy)
Amine Units	2,100
Drilling Equipment	1,197
Diesel Engines	143
Natural Gas Engines	17
Natural Gas Turbines	12
Boilers/heaters/burners	2
Flares	1
Total Emissions (tpy)	3,472

Table 8-9. Annual VOC Emission Estimates for Platform Sources.

Equipment	VOC Emissions (tpy)
Fugitives	29,826
Vents	11,897
Storage Tanks	5,627
Losses From Flashing	3,625
Glycol Dehydrators	2,572
Pneumatic Pumps	2,316
Natural Gas Engines	1,542
Pressure/Level Controllers	990
Drilling Equipment	487
Mud Degassing	353
Diesel Engines	217
Natural Gas Turbines	47
Boilers/heaters/burners	21
Loading Losses	7
Flares	8
Amine Units	1
Total Emissions (tpy)	59,536

Table 8-10. Annual Emission Estimates for Amine Units.

Pollutant	Emissions (tpy)
SO_2	2,100
VOC	1

Table 8-11. Annual Emission Estimates for Boilers/Heaters/Burners.

Pollutant	Emissions (tpy)
CO	511
NO_X	446
PM_{10}	29
$PM_{2.5}$	29
SO_x	2
VOC	21

Table 8-12. Annual Emission Estimates for Diesel Engines.

Pollutant	Emissions (tpy)
CO	894
NO_X	4,043
PM_{10}	194
$PM_{2.5}$	193
SO_X	143
VOC	217

Table 8-13. Annual Emission Estimates for Drilling Equipment.

Pollutant	Emissions (tpy)
CO	7,759
NO_X	9,783
PM_{10}	176
$PM_{2.5}$	173
SO_X	1,197
VOC	487

Table 8-14. Annual Emission Estimates for Flares.

Pollutant	Emissions (tpy)
CO	471
NO_X	90
PM_{10}	2
SO_X	1
VOC	8

Table 8-15. Annual Emission Estimates for Natural Gas Engines.

Pollutant	Emissions (tpy)
CO	80,679
NO_X	56,546
PM_{10}	241
$PM_{2.5}$	241
SO_X	17
VOC	1,542

Table 8-16. Annual Emission Estimates for Natural Gas Turbines.

Pollutant	Emissions (tpy)
CO	1,830
NO_X	7,141
PM_{10}	147
$PM_{2.5}$	147
SO_X	12
VOC	47

Table 8-17. Annual Emission Estimates for Vents.

Pollutant	Emissions (tpy)
H_2S	3
VOC	11,897

Table 8-18. Total Greenhouse Gas Emission Estimates for Platform Sources.[a]

Equipment Types	CH_4 Emissions (tpy)	CO_2 Emissions (tpy)	N_2O Emissions (tpy)
Amine Units	18	0	0
Boilers/heaters/burners	9	741,563	9
Diesel Engines	5	168,906	N/A[b]
Drilling Equipment	69	508,714	N/A
Fugitives	107,141	0	0
Lossing From Flashing	79,756	1,812	0
Mud Degassing	1,836	7	0
Natural Gas Engines	15,112	3,377,352	N/A
Natural Gas Turbines	192	2,454,703	67
Pneumatic Pumps	15,480	298	0
Pressure/level Controllers	11,796	217	0
Vents	330,780	7,047	0
Total Emissions (tpy)	562,194	7,260,619	76

[a] Emission factors for these pollutants were not available for flares, glycol dehydrators, loading losses, and storage tanks.
[b] N/A = not available.

Table 8-19. Total Greenhouse Gas Emission Estimates for for Non-Platform Sources.[a]

Category	CO_2 Emissions (tpy)	N_2O Emissions (tpy)
Biogenic/Geogenic Sources	0	1,948
Commercial Marine Vessels	1,258,433	N/A
Drilling Rigs	1,812,576	N/A
Fishing Vessels	125,749	N/A
Helicopters	130,077	N/A
LOOP	371,772	N/A
Military Vessels	302,178	N/A
Pipelaying Vessels	1,188,932	N/A
Platform Removal and Construction Vessels	244,917	N/A
Support Vessels	2,509,262	N/A
Survey Vessels	12,469	N/A
Vessel Lightering	1,380,975	N/A
Total Emissions (tpy)	9,337,340	1,948

[a] CH_4 emissions were not estimated for non-platform sources.
N/A = not available.

Table 8-20. Comparison of OCS Platform Emission Estimates.

1995 GMAQS					2000 Gulfwide Study				
NO_x (tpy)	SO_x (tpy)	TSP (tpy)	CO (tpy)	VOC (tpy)[a]	NO_x (tpy)	SO_x (tpy)	PM_{10} (tpy)	CO (tpy)	VOC (tpy)
94,483	15,869	1,720	21,988	80,374	78,049	3,472	789	92,144	59,536

[a] VOC estimate is based on U.S. DOI MMS (1995) THC value, adjusted for vented % CH_4

Table 8-21. Comparison of OCS Platform Fuel Combustion Emission Factors.

Equipment Type	1995 GMAQS					2000 Gulfwide Study				
	NO_x	SO_x	TSP	CO	THC	NO_x	SO_x	PM_{10}	CO	VOC
Natural Gas Engines [a] (lb/MMBtu)	2.71	2.86E-04	3.33E-02	5.90E-01	1.24	1.41	5.88E-04	1.20E-02	1.32	9.75E-02
Diesel Engines <600 hp (lb/1000 gal)	604	40	43	130	49	604.30	N/A	42.48	130.18	45.22
Diesel Engines >600 hp (lb/1000 gal)	425	28	10.45	111	12.3	438.49	N/A	7.8	116.47	10.96
Diesel-fired Boilers (lb/1000 gal)	20	28.5	2	5	0.2052	22	N/A	2	5	0.2
Natural Gas-fired Boilers<100 MMBtu/hr (lb/MMscf)	140	0.6	13.7	35	5.8	100[b]	0.6	7.6	84	5.5
Natural Gas-fired Boilers>100 MMBtu/hr (lb/MMscf)	550	0.6	5	40	1.7	280[b]	0.6	7.6	84	5.5

[a] Average of all NGE emission factors for 2000 study

[b] Uncontrolled emission factors only

N/A= Not applicable for this comparison (emission factors based on fuel sulfur content)

Where needed, conversions are based on 1050 Btu /scf natural gas, 7.1 lb/gal diesel fuel, and 19,300 Btu/lb

Table 8-22. Comparison of Non-Platform Emission Estimates.

Source Type	1995 GMAQS NO_x (tpy)	1995 GMAQS VOC (tpy)	1995 GMAQS CO (tpy)	2000 Gulfwide Study NO_x (tpy)	2000 Gulfwide Study VOC (tpy)	2000 Gulfwide Study CO (tpy)
Survey Vessels/Drilling Vessels	26,276	1,048	2,989	27,458	265	2,881
Support Vessels	9,709	770	2,362	37,118	542	5,104
Support Helicopters	288	212	694	1,438	2,285	6,060
Pipelaying Vessels	18,042	3,070	2,843	17,887	173	1,877
Platform Construction and Removal Vessels				3,637	49	474
OCS Non-Platform Total	54,315	5,100	8,888	87,538	3,314	16,396
LOOP	2,602	701	299	5,106	1,118	2,222
Vessel Lightering				18,839	9,525	8,740
Fishing Vessels	14,483	1,191	5,964	1,899	17	187
Military Vessels	108		12	4,592	41	451
Commercial Marine Vessels	85,961	3,745	9,563	19,487	182	1,936
Biogenic/Geogenic Sources				0	13,561	0
Non-OCS Non-Platform Total	103,154	5,637	15,838	49,923	24,444	13,536
Total Non-Platform Emissions	157,469	10,737	24,726	137,461	27,758	29,932

Table 8-23. Comparison of Commercial Marine Vessel Emission Estimates.

Study	Pollutant NO_x	Pollutant VOC	Pollutant CO
2000 Gulfwide Study			
Western & Central Gulf	19,487	182	1,936
Eastern Gulf	16,934	149	1,669
State Waters	41,054	360	4,046
Gulfwide Total	77,475	691	7,651
1995 GMAQS			
Gulfwide Total	85,961	3,745	9,563
Percentage Difference	-10%	-82%	-20%
Corbett & Fischbeck/Maritime Administration			
Gulfwide Estimated Total	65,675	1,924	5,700

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APPENDICES

GULFWIDE NON-PLATFORM EMISSION SOURCES

MEMORANDUM

TO: Dr. Chester Huang, MMS

FROM: Richard Billings, Roger Chang, Jaime Hauser, Heather Perez and Garry Brooks, ERG

DATE: October 29, 2003

SUBJECT: Gulfwide Non-Platform Emission Sources

1.0 INTRODUCTION

The Minerals Management Service (MMS) is responsible for determining if air pollutant emissions from platform and non-platform sources in the Gulf of Mexico influence the ozone attainment (and nonattainment) status of onshore areas. To this end, MMS implemented the *Gulfwide Emission Inventory Study* to develop a base year 2000 inventory of criteria pollutant and greenhouse gas emission sources in the Gulf. In addition to compiling activity data from platform operators, the Gulfwide study collected activity data and calculated emissions for a number of non-platform sources including:

- Survey Vessels,
- Drilling Rigs,
- Support Vessels,
- Support Helicopters,
- Pipe Laying Operations,
- The Louisiana Offshore Oil Platform (LOOP),
- Vessel Lightering,
- Commercial/recreational Fishing,
- Military Vessel Operations,
- Commercial Marine Vessels,
- Biogenic/Geogenic Sources, and
- Platform Construction and Removal Vessels.

Compilation of activity data has been completed for the above source categories. Based on the collected activity data, Gulfwide emission estimates for each source category are summarized in Table 1. Section 2.0 of this report summarizes the data collected and methods used to estimate emissions for each source category. Note all PM emission estimated in this report are as PM_{10}. Additional detailed data for each of the non-platform source categories are provided in the appendices of this report.

Table 1-1. Summary of Non-Platform Emission Estimates.

Source Category	Emissions (tpy)						
	PM	NO_x	SO_2	CO	VOC	CO_2	N_2O
OCS Production Related Sources							
Survey Vessels	5	188	32	19	2	12,469	*
Drilling Rigs	677	27,270	4,587	2,862	263	1,812,576	*
Support Vessels	929	37,118	6,352	5,104	542	2,509,262	*
Support Helicopters	107	1,438	177	6,060	2,285	130,077	*
Pipelaying Vessels	444	17,887	3,009	1,877	173	1,188,932	*
Platform Construction & Removal Vessels	91	3,637	620	474	49	244,917	*
OCS Total	2,253	87,538	14,777	16,396	3,314	5,898,233	
Non-OCS Production Related Sources							
LOOP	147	5,106	945	2,222	1,118	371,772	*
Vessel Lightering	550	18,839	3,505	8,740	9,525	1,380,975	*
Fishing Vessels	47	1,899	318	187	17	125,749	*
Military Vessels	129	4,592	967	451	41	302,178	*
Commercial Marine Vessels	498	19,487	3,545	1,936	182	1,258,433	*
Biogenic / Geogenic					13,561		1,948
Non-OCS total	1,371	49,923	9,280	13,536	24,444	3,439,107	1,948
Grand Total	3,624	137,461	24,057	29,932	27,758	9,337,340	1,948

* N_2O emission factors were not identified for these source categories.

Emissions data were then disaggregated to MMS lease blocks. The latest marine diesel emission factors developed by the EPA in support of recent marine diesel regulations for all marine diesel engines were used in this study. Emission factors for residual oil-fueled vessels were derived from methods used in the 1999 National Emission Inventory (NEI) Commercial Marine Vessel Documentation. Helicopter emission factors were developed specifically for this inventory and are discussed in detail in the Appendix D of this report.

Section 3.0 notes the limitations of the current study and identifies areas for potential improvement. Section 4.0 of this report provides a complete list of all references used in this inventory effort.

2.0 Summary of Non-platform Source Categories

2.1 Survey Vessels

Survey vessels are used in the Gulf of Mexico (GOM) to map geologic formations and seismic properties. These survey mapping activities are needed to evaluate potential oil reserves in the GOM. The most common survey technique uses blasts from underwater air guns. The sound wave from the air gun blasts are deflected by underground geologic strata and detected by sound wave receptors associated with the survey vessel. There are two types of surveys that can be performed (i.e., two dimensions (2-D) and three dimensions (3-D)). 3-D surveys have been the dominant and preferred exploration technique in the Gulf, though quite a few permits were issued for high resolution 2-D surveys. Most modern survey vessels tow multiple streamers (sound wave reception devices) such that for every linear mile traveled, they acquire data for a square mile of subsurface area (Brinkman 2002a, 2002b).

Survey vessel activity was provided by the Operation and Analysis Branch of the Engineering and Operations Division of MMS. Survey activities require a permit from MMS if the survey is intended for blocks not currently under lease. The Operation and Analysis Branch provided summary permit data for survey activities in these inactive lease blocks. Operators do not need to notify MMS if they intend to survey blocks they currently lease, such that the survey vessel activity used in this report underestimates actual activity. Due to issues of confidentiality, information about the location of permitted surveys could not be provided (Dellagiarino 2001).

The total hours of survey activity were estimated based on the total number of miles surveyed for 2-D surveys and total surface area surveyed for 3-D surveys. It was assumed that underway vessel speed for both 2-D and 3-D surveys is approximately 5 MPH (Brinkman 2002b).

Emissions associated with survey vessels are primarily from marine diesel engines used for propulsion and to provide electricity and compressed air to operate the survey equipment. Emissions were estimated by applying the activity hours to marine engine emission factors. The emission factors used for this source category were based on emission equations included in support of the EPA's diesel marine vessel rule (EPA 2000). These equations depend on horsepower and loading factor assumptions provided in the U.S. Department of the Interior Minerals Management Service's 1995 *Gulf of Mexico Air Quality Study (GMAQS)* (U.S. DOI, MMS 1995). Appendix A provides details concerning the activity data and emission factors used and the emission estimates calculated for survey vessels.

2.2 Drilling Rigs

Drilling rigs are vessels used for exploratory drilling to supplement the geologic information provided by survey vessels. The drilling rig drills a hole in the ocean floor by turning a drill bit attached to lengths of tubular pipe. Several different types of drill rigs operate in the GOM including jack-ups, semisubmersibles, submersibles, and drill ships. Drilling rigs vary relative to the water depth where they are intending to operate. For example, jack-ups are able to work in water up to 375 feet, semisubmersibles and submersibles operate in water with depths of 300 to 2,000 ft and drill ships operate in waters with depths greater than 2,000 ft.

The Operation and Analysis Branch of the Engineering and Operations Division of MMS provided activity data for drilling rigs by block, which included activity for jack-ups, semi-submersibles, submersibles, and drill ships (Mayes 2002).

Emissions from drilling rigs are associated with the operation of medium- to high-speed marine diesel engines that are used for propulsion, generating electricity, operating mud pumps, and draw works. MMS activity data were applied to emission factors derived from EPA marine diesel engine emission equations (EPA 2000). To use these EPA emission equations, assumptions about vessel horsepower and typical operating loads were obtained from the GMAQS. The emission factors obtained from these equations were applied to the compiled activity data to estimate emissions for the portion of GOM where MMS has lease blocks. Appendix B provides detailed information about the activity data and emission factors used in calculating emission estimates for drilling rigs.

2.3 Support Vessels

Support vessels include crew boats that transport workers to and from work sites, supply vessels that carry supplies to offshore sites, and tugs and barges that transport heavy equipment and supplies.

Data characterizing the support vessel fleet for 2000 are not available. The number of support vessels for the year 1992 was obtained from the GMAQS. In the GMAQS it was estimated that approximately 3,400 platforms were in operation (in 1992). It should be noted that the 1992 support vessel survey had a response rate of 64 percent, such that actual vessel numbers maybe larger than those reported in the study. Currently, MMS estimates that the number of active platforms is 3,987, an increase of approximately 17 percent from 1992. It is assumed that as the number of platforms increase, the support vessel fleet increases proportionally, therefore, the 1992 support vessel fleet was increased 17 percent in order to approximate the size of the 2000 support vessel fleet. The GMAQS assumed that support vessels operate 21 hours per day, this assumption was also used in this 2000 study. The vessel population estimate and the average hours of operation were used to calculate the total annual hours that support vessels operate.

Emissions associated with support vessels are attributed to the operation of the primary diesel engine used for propulsion and other smaller diesel engines that are used to run generators or small cranes and winches for loading and unloading the vessels.

The amount of time that each type of support vessel typically spends in each of the operating modes (i.e., hoteling, maneuvering, and cruising), the load factor associated with each operating mode, and typical engine horsepower rating was assumed to be the same in 2000 as was documented in the GMAQS. The operating mode times, load factors, and typical horsepower ratings were applied to the EPA marine diesel engine equations (EPA 2000) to obtain representative emission factors. These emission factors were applied to the activity data to estimate emissions. Appendix C provides detailed information about the activity data and emission factors used to estimate emissions from support vessels.

2.4 Helicopter Traffic

Helicopters are used extensively in the GOM to move light supplies and personnel to and from platforms. Activity data for 2000 were obtained from the *Helicopter Safety Advisory Conference's (HSAC) Gulf of Mexico Offshore Helicopter Operations and Safety Review.* This reference provided data on the number of helicopter trips taken, number of passengers carried, and duration of trips. The activity data were disaggregated into single engine, twin engine, and heavy twin engine helicopters.

The average trip length was relatively short (16 minutes) (HSAC 2001); it is assumed that helicopters typically hop from platform to platform, therefore the emission estimates are based on a short landing and take off (LTO) cycle that is appropriate for the documented average trip length. Gulfwide activity was estimated by applying the number of helicopter trips to the average trip time to get total hours of operation.

The helicopter emission factors were obtained from multiple sources including the *Final Air Quality Management Plan, 1991 Revision, Final Technical Report III-G, 1987 Aircraft Emission Inventory in the South Coast Air Basin* developed by the California South Coast Air Quality Management District. Staff at the California Air Resources Board noted that these emission factors have not been updated since 1991. Additional helicopter emission factors were obtained from U.S. EPA's *Procedures for Emission Inventory Preparation Volume IV: Mobile Sources* (EPA 1992), as well as data from the Allison helicopter engine manufacturer, and helicopter test data from the Department of the Navy's *Environmental Assessments* (Department of Navy 1999). Staff at the EPA's Office of Transportation and Air Quality (OTAQ) were contacted to insure that all data sources of helicopter emission factors were identified in this effort.

The emission factors were disaggregated into the helicopter types used in the HSAC's activity data. LTO-based emission factors for each helicopter type were averaged providing the emission factors used in this study. The data obtained for military helicopters were not included in the average for two reasons. First, some of the emission factors were more than an order of magnitude different from the factors obtained from other data sources and a credible explanation for the difference could not be provided. Second, most of the helicopters used to support oil platform activities are commercial, not military helicopters.

The helicopter activity data were applied to the emission factors developed in this study to estimate emissions from this source category. Appendix D provides detailed information about the activity data and emission factors used to calculate helicopter emission estimates.

2.5 Pipelaying Vessels

Product from oil platforms is generally transported to shore via pipeline. New pipeline is constantly being laid linking new platforms to shore. Pipelines also require occasional maintenance and repair. To install, maintain, or replace sections of pipeline necessitates considerable vessel support. The GMAQS estimated the number of vessels needed to lay a given length of pipe in 24 hours. From these assumptions, it was calculated that it takes 0.4 total vessel hours to lay one foot of pipe. This value was applied to the geographic information system (GIS) data provided by the MMS Pipeline Section to estimate hours of operation. The MMS data documents the length and location of individual sections constructed or maintained from January 1 to December 31, 2000 (Froomer 2002).

Emissions associated with pipelaying vessels are attributed to the operation of the primary diesel engine used for propulsion and other smaller diesel engines that are used to run generators, air compressors, welding equipment, or small cranes and winches. Releases of gas or oil from pipelines that required repair or accidental releases during construction or maintanance were not considered in this study.

Assumptions about average horsepower and load factors were obtained from the GMAQS and applied to EPA emission equations (EPA 2000). This provided an hourly emission factor that was applied to the calculated hours of operation to estimate emissions. Appendix E provides detailed information about the activity data and emission factors used to calculate emission estimates for pipelaying vessels.

2.6 LOOP

The Louisiana Offshore Oil Port (LOOP) is a platform located 18 miles south of Grand Isle, Louisiana. This offshore port allows large oil tankers to unload product without having to navigate into and out of a port. The LOOP consists of several emission sources: one 1000 kW generator, four 7,500 hp pumps, support vessels, as well as the oil tankers that use the facility.

Hours of operation for the generator, pumps, and vessels were obtained from the LOOP's website (www.loopllc.com). This site also included detailed information about the individual vessels that used the platform in 2000 and the line vessels that assisted the oil tankers in getting to and from the mooring points.

The LOOP website also provided detailed geographic data identifying the shipping approach used by vessels, the waiting area, and the mooring points as well as latitude and longitude coordinates for the platform itself.

Marine diesel emission factors were developed for each emission source associated with the LOOP based on new EPA emission equations developed in support of the recent marine diesel engine rules (EPA 2000). To develop specific emission factors for the LOOP's marine diesel engines, it was necessary to use average engine horsepower and assumptions about engine load factors provided in the GMAQS. The hours of operation were applied to these emission factors to estimate emissions from the diesel sources associated with the LOOP.

Vessels also emit VOCs through evaporative losses from tanker ballasting operations. Ballasting is the pumping of water into a vessel after the product has been removed, the added water improves the stability of a tanker. As water is pumped into a vessel, volatile organics are displaced. Evaporative emissions from ballasting were also calculated in this effort. These estimates were derived from product transfer data for each vessel that used the LOOP and emission factors included in the EPA Emission Inventory Improvement Program (EIIP) guidance documents.

Appendix F provides detailed information about the activity data and emission factors used to calculate emission estimate for all emissions sources associated with the LOOP.

2.7 Lightering

Lightering is the transfer of cargo to smaller ships that bring the product into port. Lightering occurs off-shore in three designated areas, which are defined by latitude and longitude coordinates. Emissions associated with lightering are attributed to primary propulsion engines of the vessels involved in lightering, secondary engines (e.g., pumps and winches), and evaporative emissions associated with ballasting and product transfer.

The Coast Guard is responsible for monitoring lightering activities and was the data source for the GOM vessel lightering activity data used in this report. To calculate the emissions from the ships involved in the lightering process, the activity data provided, which included hours of operation and number of vessels, were compiled and applied to diesel emission factors derived from EPA marine diesel engine equations. These equations used assumptions about engine horsepower and load factors that were obtained from the GMAQS.

Organic vapors are displaced into the atmosphere while ships ballast or while transferring product into the escort vessels. In this report, activity data were collected to quantify ballasting and estimate associated emissions. Appendix G provides detailed information about the activity data and emission factors used to calculate emission estimates for all sources associated with lightering activities.

2.8 Commercial Fishing/Recreational Fishing

The GOM is an active commercial fishing area, providing a wide range of fish and seafood products. Detailed commercial fishing data were obtained from the National Oceanic & Atmospheric Administration's National Marine Fisheries Service (NMFS). Separate activity data were provided for the three different types of offshore fishing activities that occur in the GOM, pelagic long line, reef, and shrimp fishing operations (Cramer 2001, Pattela 2001, Poffenberger, 2001). The activity data for these different fishing operations were provided as latitude and longitude for pelagic long line fishing operations and NMFS' geographic grid for reef and shrimp fishing. The associated activity data were provided in terms of hours of operation and can be applied directly to emission factors to estimate emissions.

Emissions associated with commercial fishing vessels are attributed to the operation of diesel engines used for propulsion and other smaller diesel engines that are used to run generators or small cranes and winches to lift fish nets and lines onto the vessel.

Assumptions about fishing vessel horsepower and typical load factors were provided in the GMAQS. This information was applied to EPA marine diesel emission equations (EPA 2000) to derive emission factors. These emission factors were applied to the hours of operation provided by the NMFS to calculate emissions for this source category.

Appendix H provides detailed information about the activity data and emission factors used in calculating emission estimate for commercial fishing operations.

After careful study, it was decided that the majority of recreational fishing occurs within state waters and therefore this source category was not included in this inventory. It is recognized that some small portion of recreational fishing occurs near platforms that are not in state waters. Unfortunately, data could not be identified to quantify recreational fishing near oil platforms.

2.9 Military Vessel Operations

The U.S. Navy and Coast Guard frequently patrol and have manuevers in the GOM. The U.S. military vessel fleet consists of vessels powered by a variety of engines including older residual fueled steam turbines, marine diesel engines, and high speed diesel turbines.

Contacts were made with the Navy to obtain activity data necessary to estimate vessel emissions. Despite these repeated data requests and promises to provide the required data, the Navy has not submitted any activity data at this time. Therefore, the data the Navy provided for the GMAQS were used in this inventory. It was assumed that naval vessel activity remained constant during this period and no adjustments were made to the activity data. Hours of operation for each vessel were assumed to be 24 hours per day, 365 days per year.

Navy vessel emission estimates were developed for marine diesel engines using the EPA marine diesel equations. A load factor of 80% was assumed and engine horsepower for each vessel was obtained in the GMAQS.

Steamship and turbine engine vessel emission estimates were determined differently. Fuel consumption data for these vessel types were supplied by the Navy in the GMAQS. Emissions factors for residual oil-fueled steamship vessels were obtained from the EPA's *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and other Nonroad Components of the National Emission Inventory* (EPA 2003). For turbine-powered vessels, updated emission factors were obtained from the EPA's AP-42, Volume 1, Chapter 3 for turbines operating with distillate fuels (EPA 2002).

The Coast Guard provided data that included the number of boats operating in the GOM, the type of boat, the number of engines, and horsepower of each engine, the total number of operating hours for each, and the percentage of time each vessel spent in the OCS (McClellan 2002, Peschke 2002, Thomas 2001). From this data, the total number of operating hours was calculated for each type of boat. Assuming a load factor of 80%, and using the provided horsepower data, emission factors were derived using the EPA's marine diesel equations (EPA 2000). Emissions from each boat type were calculated and totaled to estimate emissions for all Coast Guard vessels operating in the Gulf.

Appendix I provides detailed information about the activity data and emission factors used to the calculate the emission estimate for military vessels.

2.10 Commercial Marine Vessels

Commercial marine vessels (CMV) are involved in transporting a wide range of agricultural, manufacturing, and chemical products through the Gulf. CMVs tend to be powered by either diesel engines that combust diesel or residual oil fuels or steam ships that burn residual fuel. Though some emissions may occur due to evaporative losses of volatile chemical products, most of the emissions associated with CMVs are from the combustion of the fuels used to propel the marine vessels.

In this inventory of non-platform emission sources, CMV emission estimates for diesel-powered vessels were estimated by using ton-mileage emission factors developed from EPA data (EPA 2003) and ship lane activity data obtained from the Army Corps of Engineers. Steamship emission estimates were extrapolated from the EPA's NEI (EPA 2003).

Appendix J provides detailed information about the activity data and emission factors used to calculate emission estimates for CMVs.

2.11 Biogenics/Geogenic Emission Sources

Emission estimates for seeps of crude oil (MacDonald et al. 1993, Kennicutt 1989, Mitchell 1999) and subsurface bacterial processes (Nevison et al. 1995, Bouwman 1995) were calculated. However, oceanic processes venting of natural gas, and emissions from methane hydrates could not be estimated in this study because useful quantitative information could not be found during this project's literature search.

Appendix K provides detailed information about the methods used to estimate emissions from oil seepage. This appendix is somewhat different than the other appendices as it summarizes much of the current literature on this topic. It is hoped that in the future this information will be valuable to estimate emissions from biogenic and geogenic sources.

2.12 Platform Construction and Removal

A variety of vessels are needed to transfer equipment, materials, and structural platform components, as well as workers and technicians, during the construction and removal of offshore oil platforms. The methods used to estimate emissions from these vessels were adapted from another MMS study, *Emission Inventories of OCS Production and Development Activities in the Gulf of Mexico – Final Report* (Coe et al. 2003). As the vessels involved in platform construction and removal activities are similar to support vessels discussed in Appendix C of this report, many of the same assumptions about vessel characteristics and operations were used to estimate emissions.

Platforms that were installed or removed during 2000 were identified using MMS's platform structure database. Additional data were provided by MMS quantifying the water depth at the platform and the number of pilings associated with individual platforms. This information was used in conjunction with data included in Coe et al. (2003), to estimate the total vessel hours associated with platform construction and removal. Assumptions about typical vessel horsepower and operating loads used in the support vessel calculations were also used to develop emission factors for vessels associated with this source category. These hourly emission factors were applied to the estimate of total vessel hours of operation to calculate total emissions. For more details regarding the calculation of emissions for vessels involved in platform construction and removal see Appendix L.

2.13 Spatial Allocation of Emissions

Appendix M documents the methods used to spatially allocate emissions to MMS lease blocks. The approach varied by source category to insure that the most appropriate surrogates were used. For example, the survey vessel emission estimates were only for non-active lease blocks, therefore, emissions were allocated to non-active lease blocks based on their surface area. For drilling rigs, activity data were provided for individual blocks, therefore emissions could be allocated to lease blocks based on hours of operation. Support vessel emissions were allocated to lease blocks with active platforms, while support helicopter emissions were allocated to lease blocks with active platforms that had helipads. MMS maintains a GIS data set of 2000 pipeline activities. Pipeline emissions were allocated based on the length of pipeline constructed or maintained within the lease block boundaries. Similarly, for platform construction and maintenance activities, MMS maintains a data set that includes the date of installation or removal and the platform latitude and longitude coordinates. Emissions were assigned to individual platforms based on the estimated hours of operation calculated for the platform's construction or removal.

Similar approaches were used to spatially allocate emissions to non-OCS production related sources. For example, the LOOP provided information to accurately map vessel approach shipping lanes, as well as latitude and longitude coordinates for the platform itself. Vessel lightering emissions were spatially allocated relative to the vessel type and the activity. Where product was off loaded, emissions were allocated to the centroid of the lightering zone. For emissions associated with escort vessels shuttling product to port, the fairway was mapped and emissions allocated to associated lease blocks based on the length of the vessel fairway within the lease block boundaries. Commercial fishing emissions were applied to lease blocks associated with NMFS's fishing areas based on the activity data provided. Military vessel emissions and biogenic and geogenic emissions were applied to all northern Gulf federal waters based on the amount of surface area associated with each lease block. For these two source categories it was assumed that the emissions were spread over the whole region including MMS's western, central, and eastern Gulf areas. (Note, Table 1 only summarizes emissions associated with the western and central MMS areas.) Commercial marine vessel emissions were allocated to shipping lanes based on cargo traffic; these emissions were allocated to individual lease blocks based on the length of shipping lane within the lease block boundaries. For more details on the spatial allocation procedures used, see Appendix M.

3.0 Limitations of the Non-platform Inventory

As with the development of any inventory of activity data or emission estimates, the accuracy of the study can vary considerably depending upon the accuracy of the activity data obtained and the emission factors used.

For some source categories, such as the LOOP, commercial fishing, and the Coast Guard, the activity data used in this study were specific and reasonably accurate for the 2000 base year. But many of the other source categories are based on adjustments made to activity data that were included in the earlier GMAQS. Much of the non-platform activity data used in the 1995 study were derived from a 1992 Survey of Offshore Operators undertaken by the Offshore Operators Committee. This 1992 report contains useful information, and it would have been helpful if a similar study could have been performed for this 2000 inventory effort.

Given the methods used to calculate the emission estimates, an important factor influencing the quality of the estimate is the validity of the emission factors, both in terms of absolute accuracy, as well as representativeness for each source type. Most of the non-platform sources are powered by marine diesel engines. In this study, marine diesel emission factors were developed using recent EPA emission factor equations derived from a large number of “in use” vessel test data. These emission factor equations require horsepower and operating load factors. Typical horsepower and load factors were obtained from the GMAQS. These values are considered averages such that actual emissions from specific vessels may be significantly different than emissions from an average vessel.

As with most inventory efforts, use of better quality data can improve the accuracy of the emission estimates. Improvements can be made in this study in the following areas:

- If the 1992 Survey of Offshore Operators developed by the Offshore Operators Committee is revised, the new data will help clarify whether vessels involved with platform construction and removal are included. Data from the updated survey should be incorporated into this inventory;

- Rather than use typical horsepower rating, it is recommended that horsepower ratings should be compiled for individual survey vessels, drilling rigs, pipelaying vessels, and commercial fishing boats;

- The Navy activity data needs to be updated to represent actual 2000 activity;

- Helicopter data needs to be collected for the Navy and Coast Guard operations;

- The helicopter emission factors should be updated as new data become available; and

- The biogenic and geogenic estimating procedures should be updated as new data become available.

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APPENDIX A

SURVEY VESSELS

Due to issues of confidentiality only limited activity data were available for survey vessels. The Operation and Analysis Branch of the Engineering and Operations Division of MMS does not keep records of survey vessels operating in areas which are leased to an operator, nor can they release information on recent individual survey permits (Dellagiarino 2001). However, summary survey information is available through the U.S Department of the Interior's Minerals Management Service's Resource Evaluation Division's *Geological and Geophysical Data Acquisition-Outer Continental Shelf through 2000* report (U.S. DOI, MMS 2001). The report contained the number of miles and/or blocks that had been surveyed, prior to lease sale, during 2000. This information is divided into the two types of survey's implemented in the Gulf, 2-D seismic surveys and 3-D seismic surveys.

Web sites of companies who do seismic surveying in the GOM were viewed to obtain data on the number of engines a survey vessel generally has (Fugro GeoServices, Inc. 2002). Typical survey vessel cruising speed (5 mph) was provided by MMS staff (Brinkman 2002a, 2002b). By dividing the number of miles surveyed by the vessel cruising speed, the number of operating hours were estimated for each survey type, as shown in Table A-1.

The average horsepower of survey vessels was obtained from the GMAQS, and was applied to the 2000 inventory. A load factor of 80 percent was assumed based on engineering judgement. The total engine hours operated, the average load factor, and the average horsepower were applied to the following emission equations from the U.S. EPA's *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* (EPA 2000) in order to derive a representative emission factor.

$$E\ (\text{g/kW-hr}) = A * (\text{Load Factors})^{-x} + B$$

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables A-2, and A-3 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA, 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

Example Calculation

$$\begin{aligned} E_{PM} &= 0.01\ (\text{Operating load})^{-1.5} + 0.26 \\ &= 0.01\ (0.80)^{-1.5} + 0.26 \\ &= 0.27\ \text{g/kW-hr} \end{aligned}$$

For SO_2, it is necessary to first calculate *Fuel Consumption* using the following equation:
Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A* (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). It should be noted that the A coefficient for the sulfur emission estimate was corrected in this study to 1.9899 (which is rounded to 2.00), based on discussions with EPA staff concerning the correct value that should be used.

Tables A-2 and A-3 show how the emission factors were developed. The emission factors reported in these tables do not always agree with the coefficients, due to round-off error. These emission factors were applied to the hours of operation and typical horsepower to estimate emissions.

Example Calculation

Emission Estimate = E_{PM} * Average Kw Rating * Total Engine Hours
= 0.27 g/kW-hr * 578.66 kW * 25,884 hours
= 3,894 Kg
= 4.29 Tons

These emission estimates for both 2-D and the 3-D survey vessels were added together to get the total estimate of emissions from surveying vessels shown in Table A-4.

Table A-1. Calculation of Hours Worked.

2D Survey Vessels		
Miles Surveyed in 2000	Speed of Vessel (mi/hr)	Number Hrs Req'd to Survey all Miles
64,710	5	12,942

3D Survey Vessels			
Blocks Surveyed in 2000	Miles Surveyed*	Speed of Vessel (mi/hr)	Number Hrs Req'd to Survey all Blocks
1,578	4,734	5	946.8

*Assumption that it requires 3 miles to survey 1 block.

Table A-2. Activity Data and Emission Factors for Survey Vessels - 2D Seismic.

Summary Data for Survey Vessels-2D Seismic				
Engines	Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
2	80%	776	578.66	25,884

Emission Factors for Survey Vessels-2D Seismic							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Average kW rating	Kg/hr	lbs/hr
PM	0.27	1.50	0.26	0.01	578.66	0.15	0.34
NO_x	10.62	1.50	10.45	0.13	578.66	6.15	13.55
SO_2*	1.78	N/A	0.00	2.00	578.66	1.03	2.27
CO	1.05	1.00	0.00	0.84	578.66	0.61	1.34
VOC	0.09	1.50	0.00	0.07	578.66	0.05	0.12
CO_2	703.73	1.00	648.60	44.10	578.66	407.22	897.76

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table A-3. Emission Factors for Survey Vessels - 3D Seismic.

Summary Data for Survey Vessels-3D Seismc				
Engines	Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
2	80%	776	578.66	1,893.60

Emission Factors for Survey Vessels-3D Seismic							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Average kW rating	Kg/hr	lbs/hr
PM	0.27	1.50	0.26	0.01	578.66	0.15	0.34
NO_x	10.62	1.50	10.45	0.13	578.66	6.15	13.55
SO_2*	1.78	N/A	0.00	2.00	578.66	1.03	2.27
CO	1.05	1.00	0.00	0.84	578.66	0.61	1.34
VOC	0.09	1.50	0.00	0.07	578.66	0.05	0.12
CO_2	703.73	1.00	648.60	44.10	578.66	407.22	897.76

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table A-4. Summary of Total Emission Estimates for Survey Vessels.

Pollutant	2D Seismic	3D Seismic	Total
	Emissions (tons/year)		
PM	4.35	0.32	4.67
NO_x	175.42	12.83	188.26
SO_2	29.40	2.15	31.55
CO	17.29	1.26	18.56
VOC	1.54	0.11	1.65
CO_2	11,618.77	850.00	12,468.76

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APPENDIX B

DRILLING RIGS

The Operation and Analysis Branch of the Engineering and Operations Division of MMS provided detailed rig activity data by block (Mayes 2002). Separate activity data were provided for the five different types of Mobile Offshore Drilling Units (MODUs) that are used in the GOM: barges, drill ships, jack-up rigs, semisubmersible rigs, and submersible rigs. Barges operate in swallow waters, which were assumed to be within the 3-mile state waters and not included in this study. Table B-1 summarizes the provided activity data.

The hours of operation for each of the four different drilling rigs were applied to diesel emission factors based on new EPA emission factor equations. These marine diesel emission factors are based on the following linear algorithm:

E (g/kW-hr) = A * (Load Factors) $^{-x}$ +B

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables B-2, B-3, B-4 and B-5 were obtained from Table 5-1 of the U.S. EPA report *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For SO_2, it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A* (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

These power-based emission factors were applied to average horsepower ratings for the different drilling rigs and hours of operation to estimate emissions. This emission estimating approach used assumptions about horsepower and load factors provided in the GMAQS (U.S. DOI, MMS 1995). Table B-6 summarizes the emission estimates for each of the different types of drilling rigs included in this study.

Table B-1. Vessel Rig Activity.

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
DS	AT	24	*Falcon Deepwater Pathfinder*	06/26/00	08/14/00	50	1200
DS	AT	336	*Falcon Deepwater Millennuim*	03/16/00	05/26/00	72	1728
DS	GB	460	*Transocean Discoverer Spirit*	09/05/00	09/14/00	10	240
DS	GB	783	*Falcon Deepwater Pathfinder*	08/15/00	10/20/00	67	1608
DS	GB	783	*Falcon Deepwater Pathfinder*	10/20/00	11/15/00	27	648
DS	GB	783	*Falcon Deepwater Pathfinder*	11/15/00	12/10/00	26	624
DS	GC	506	*Glomar Explorer*	12/16/00	12/31/00	16	384
DS	GC	743	*Glomar C.R. Luigs*	04/22/00	10/16/00	178	4272
DS	GC	782	*Transocean Discoverer 534*	01/01/00	02/15/00	46	1104
DS	MC	305	*Transocean Discoverer 534*	02/15/00	04/14/00	60	1440
DS	MC	348	*Falcon Deepwater Millennium*	01/01/00	02/09/00	40	960
DS	MC	776	*Transocean Discoverer 534*	04/14/00	09/05/00	145	3480
DS	MC	822	*Discoverer Enterpri*	01/01/00	06/10/00	162	3888
DS	MC	822	*Discoverer Enterpri*	06/28/00	12/06/00	162	3888
DS	MC	876	*Falcon Deepwater Pathfinder*	12/11/00	12/31/00	21	504
DS	ST	250	*Glomar C.R. Luigs*	11/15/00	12/27/00	43	1032
DS	WR	165	*Falcon Deepwater Millennium*	02/09/00	03/15/00	36	864
DS	WR	425	*Glomar C.R. Luigs*	10/16/00	10/19/00	4	96
DS	WR	456	*Glomar Explorer*	07/05/00	12/12/00	161	3864
DS	WR	678	*Discoverer Spirit*	09/18/00	12/31/00	105	2520
JU	BA	437	*Falcon Seahawk*	07/16/00	07/24/00	9	216
JU	BA	577	*Pride Louisiana*	04/28/00	06/21/00	55	1320
JU	BA	A 1	*R&B Falcon 254*	09/16/00	10/28/00	43	1032
JU	BA	A 19	*Pride Alabama*	01/01/00	03/02/00	62	1488
JU	BA	A 71	*Pride Arkansas*	02/14/00	03/01/00	17	408
JU	EC	33	*Pool 53*	10/03/00	10/26/00	24	576
JU	EC	38	*Marine III*	03/13/00	04/20/00	39	936
JU	EC	60	*Diamond Ocean Columbia*	01/01/00	02/03/00	34	816
JU	EC	65	*Falcon 18*	01/01/00	04/24/00	115	2760
JU	EC	83	*Marine XVI*	02/15/00	04/09/00	55	1320
JU	EC	84	*Glomar Main Pass I*	01/06/00	03/17/00	72	1728
JU	EC	122	*Hercules 22*	03/20/00	05/10/00	52	1248
JU	EC	151	*Pride Louisiana*	01/01/00	01/04/00	4	96

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	EC	161	*Falcon 19*	06/27/00	07/18/00	22	528
JU	EC	192	*Rowan California*	09/04/00	12/31/00	119	2856
JU	EC	195	*Falcon 85*	01/10/00	05/21/00	133	3192
JU	EC	224	*Cliff Drilling 152*	04/07/00	05/08/00	32	768
JU	EC	245	*Rowan Houston*	05/22/00	06/13/00	23	552
JU	EC	263	*Marine 304*	12/30/00	12/31/00	2	48
JU	EC	275	*Marine XVI*	01/01/00	01/16/00	16	384
JU	EC	275	*Pride Colorado*	10/02/00	10/28/00	27	648
JU	EC	282	*Pride Oklahoma*	11/03/00	11/14/00	12	288
JU	EC	283	*Pride Oklahoma*	10/01/00	10/16/00	16	384
JU	EC	305	*Marine XVI*	08/03/00	08/17/00	15	360
JU	EC	305	*Marine XVI*	08/04/00	08/18/00	15	360
JU	EC	305	*Marine XVI*	09/29/00	10/08/00	10	240
JU	EC	313	*Ensco 55*	08/21/00	08/25/00	5	120
JU	EC	313	*Ensco 55*	08/25/00	12/31/00	129	3096
JU	EC	332	*Rowan Middletown*	01/01/00	02/20/00	51	1224
JU	EC	344	*Ensco 67*	02/05/00	03/11/00	36	864
JU	EC	347	*Rowan Charles Rowan*	01/11/00	01/30/00	20	480
JU	EC	347	*Rowan Gilbert Rowe*	11/09/00	12/01/00	23	552
JU	EC	364	*Chiles Columbus*	10/22/00	10/25/00	4	96
JU	EC	364	*Ensco 67*	01/08/00	02/01/00	25	600
JU	EI	28	*Cliff Drilling 150*	02/03/00	03/14/00	41	984
JU	EI	28	*Cliff Drilling 150*	03/14/00	04/14/00	32	768
JU	EI	45	*Ensco 64*	09/05/00	09/29/00	25	600
JU	EI	45	*Ensco 64*	09/29/00	11/15/00	48	1152
JU	EI	45	*Ensco 64*	11/15/00	12/10/00	26	624
JU	EI	56	*Hercules 14*	07/23/00	08/24/00	33	792
JU	EI	57	*Cliff Drilling 150*	01/01/00	02/02/00	33	792
JU	EI	71	*Hercules 25*	03/24/00	04/07/00	15	360
JU	EI	87	*Rowan Texas*	03/28/00	05/30/00	64	1536
JU	EI	88	*Diamond Ocean Titan*	06/21/00	06/21/00	1	24
JU	EI	88	*Nabors Dolphin 105*	06/15/00	07/13/00	29	696
JU	EI	95	*Nabors Dolphin 105*	07/24/00	08/07/00	15	360
JU	EI	95	*Nabors Dolphin 105*	08/29/00	09/20/00	23	552
JU	EI	95	*Nabors Dolphin 105*	09/20/00	10/16/00	27	648
JU	EI	97	*Glomar High Island VIII*	09/28/00	10/16/00	19	456
JU	EI	98	*Rowan Texas*	05/31/00	07/09/00	40	960
JU	EI	105	*Glomar High Island VIII*	02/06/00	03/11/00	35	840
JU	EI	105	*Nabors Dolphin 106*	05/14/00	05/24/00	11	264
JU	EI	105	*Nabors Dolphin 106*	08/31/00	09/12/00	13	312
JU	EI	105	*Sundowner Dolphin 106*	05/12/00	05/24/00	13	312
JU	EI	106	*Glomar High Island VIII*	11/23/00	12/31/00	39	936

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	EI	119	*Glomar High Island VIII*	07/23/00	09/25/00	65	1560
JU	EI	119	*Nabors Dolphin 105*	10/16/00	12/03/00	49	1176
JU	EI	147	*Marine 225*	05/05/00	06/13/00	40	960
JU	EI	156	*Ensco 84*	02/25/00	05/26/00	92	2208
JU	EI	156	*Ensco 84*	04/12/00	05/31/00	50	1200
JU	EI	156	*Ensco 84*	05/03/00	06/16/00	45	1080
JU	EI	156	*Rowan Juneau*	12/31/00	12/31/00	1	24
JU	EI	162	*Ensco 51*	02/06/00	03/01/00	25	600
JU	EI	189	*R&B Falcon 251*	12/23/00	12/31/00	9	216
JU	EI	199	*Marine 301*	01/01/00	03/06/00	66	1584
JU	EI	202	*Marine XVIII*	01/12/00	02/16/00	36	864
JU	EI	202	*Marine XVIII*	02/16/00	02/18/00	3	72
JU	EI	202	*Marine XVIII*	02/18/00	02/25/00	8	192
JU	EI	202	*Marine XVIII*	02/25/00	03/13/00	18	432
JU	EI	202	*R&B Falcon 253*	11/03/00	11/13/00	11	264
JU	EI	203	*Glomar Main Pass I*	01/01/00	01/02/00	2	48
JU	EI	224	*Diamond Ocean King*	05/26/00	08/30/00	97	2328
JU	EI	224	*Diamond Ocean King*	08/30/00	11/22/00	85	2040
JU	EI	224	*Diamond Ocean King*	11/25/00	12/31/00	37	888
JU	EI	227	*R&B Falcon 253*	11/13/00	12/04/00	22	528
JU	EI	247	*Marine 225*	10/04/00	10/24/00	21	504
JU	EI	271	*Ensco 67*	01/01/00	01/07/00	7	168
JU	EI	271	*Ensco 67*	08/01/00	08/11/00	11	264
JU	EI	288	*Glomar Adriatic IV*	02/12/00	03/24/00	42	1008
JU	EI	297	*Marine XV*	01/25/00	02/06/00	13	312
JU	EI	307	*Noble Johnnie Hoffman*	01/05/00	01/05/00	1	24
JU	EI	307	*Noble Johnnie Hoffman*	01/12/00	02/29/00	49	1176
JU	EI	315	*Glomar Adriatic IV*	05/11/00	06/16/00	37	888
JU	EI	333	*Rowan Paris*	06/21/00	08/22/00	63	1512
JU	EI	362	*Rowan-Alaska*	09/01/00	09/15/00	15	360
JU	EI	385	*Rowan Arch Rowan*	05/01/00	05/21/00	21	504
JU	EI	385	*Rowan Arch Rowan*	05/21/00	09/30/00	133	3192
JU	EI	385	*Rowan Arch Rowan*	09/30/00	12/01/00	63	1512
JU	EW	305	*Ensco 69*	03/12/00	09/01/00	174	4176
JU	GA	209	*Ensco 89*	02/11/00	03/09/00	28	672
JU	GA	389	*Ensco 83*	09/07/00	10/12/00	36	864
JU	GA	418	*R&B Falcon C.E.Thornton*	10/12/00	12/04/00	54	1296
JU	GC	165	*Diamond Ocean Columbia*	08/29/00	12/01/00	95	2280
JU	GI	31	*R&B Falcon 203*	09/04/00	11/20/00	78	1872
JU	GI	41	*Marine XV*	02/23/00	03/21/00	28	672
JU	GI	41	*Marine XV*	02/23/00	05/25/00	93	2232
JU	GI	68	*Glomar Adriatic IX*	01/01/00	03/01/00	61	1464

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	GI	77	*Marine IV*	12/16/00	12/31/00	16	384
JU	GI	85	*Marine XV*	01/01/00	01/19/00	19	456
JU	GI	85	*Marine XV*	01/01/00	01/05/00	5	120
JU	GI	93	*Diamond Ocean Concord*	07/15/00	07/29/00	15	360
JU	GI	94	*Diamond Ocean Warwick*	08/02/00	08/02/00	1	24
JU	GI	103	*Ensco 68*	01/17/00	04/18/00	93	2232
JU	GI	103	*Rowan-Alaska*	06/08/00	08/29/00	83	1992
JU	GI	106	*Chiles Magellan*	03/03/00	05/06/00	65	1560
JU	GI	109	*Ensco 68*	05/27/00	06/14/00	19	456
JU	GI	109	*Ensco 68*	08/20/00	09/05/00	17	408
JU	GI	109	*Ensco 68*	09/24/00	10/17/00	24	576
JU	GI	116	*Rowan Gorilla VI*	09/10/00	12/28/00	110	2640
JU	GI	116	*Rowan Gorilla VI*	12/28/00	12/31/00	4	96
JU	HI	37	*Marine IV*	04/22/00	11/03/00	196	4704
JU	HI	71	*Pool 50*	04/06/00	04/14/00	9	216
JU	HI	85	*Rowan Halifax*	04/07/00	05/14/00	38	912
JU	HI	90	*Marine IV*	11/05/00	11/30/00	26	624
JU	HI	115	*R&B Falcon 202*	08/19/00	11/02/00	76	1824
JU	HI	131	*Nabors Dolphin 105*	12/05/00	12/31/00	27	648
JU	HI	132	*R&B Falcon 204*	11/01/00	12/31/00	61	1464
JU	HI	154	*Chiles Columbus*	01/01/00	03/13/00	73	1752
JU	HI	162	*Marine 301*	10/02/00	12/31/00	91	2184
JU	HI	202	*Cliff Drilling 152*	11/13/00	12/31/00	49	1176
JU	HI	202	*Ensco 64*	01/01/00	05/08/00	129	3096
JU	HI	202	*Pride Wyoming*	05/22/00	09/19/00	121	2904
JU	HI	235	*Falcon Phoenix I*	07/10/00	08/24/00	46	1104
JU	HI	A 3	*Diamond Ocean Titan*	12/08/00	12/31/00	24	576
JU	HI	A 3	*R&B Falcon C.E.Thornton*	03/29/00	12/31/00	278	6672
JU	HI	A 3	*R&B Falcon C.E.Thornton*	12/04/00	12/31/00	28	672
JU	HI	A 5	*Marine IV*	01/01/00	01/20/00	20	480
JU	HI	A 7	*Marine III*	08/09/00	12/15/00	129	3096
JU	HI	A 7	*Marine III*	12/15/00	12/31/00	17	408
JU	HI	A 20	*Chiles Magellan*	08/10/00	12/31/00	144	3456
JU	HI	A 232	*R&B Falcon 253*	12/24/00	12/31/00	8	192
JU	HI	A 244	*Pride Arkansas*	01/01/00	02/09/00	40	960
JU	HI	A 327	*R&B Falcon F.G.Mclintock*	08/04/00	09/24/00	52	1248
JU	HI	A 343	*Rowan Louisiana*	11/05/00	11/11/00	7	168
JU	HI	A 343	*Rowan Louisiana*	11/11/00	11/30/00	20	480
JU	HI	A 354	*Chiles Magellan*	01/01/00	02/29/00	60	1440
JU	HI	A 415	*Noble Tom Jobe*	03/04/00	05/31/00	89	2136
JU	HI	A 441	*Marine XVI*	09/07/00	09/24/00	18	432
JU	HI	A 442	*Falcon 18*	04/24/00	05/14/00	21	504

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	HI	A 442	*Marine IV*	03/27/00	03/30/00	4	96
JU	HI	A 442	*Pride Texas*	10/26/00	11/17/00	23	552
JU	HI	A 465	*Diamond Ocean Nugget*	01/11/00	01/17/00	7	168
JU	HI	A 472	*Marine XVI*	11/03/00	11/30/00	28	672
JU	HI	A 472	*Marine XVI*	11/30/00	12/20/00	21	504
JU	HI	A 472	*Marine XVI*	12/22/00	12/31/00	10	240
JU	HI	A 497	*Glomar Adriatic X*	04/06/00	04/17/00	12	288
JU	HI	A 517	*Rowan Charles Rowan*	09/01/00	12/01/00	92	2208
JU	HI	A 521	*Marine III*	04/20/00	04/27/00	8	192
JU	HI	A 523	*Glomar Adriatic X*	03/08/00	04/03/00	27	648
JU	HI	A 530	*R&B Falcon F.G.Mclintock*	09/24/00	12/04/00	72	1728
JU	HI	A 554	*Ensco 60*	11/22/00	12/12/00	21	504
JU	HI	A 567	*Ensco 60*	09/05/00	11/21/00	78	1872
JU	MI	519	*Ensco 93*	12/23/00	12/31/00	9	216
JU	MI	670	*R&B Falcon 254*	10/28/00	12/31/00	65	1560
JU	MI	704	*Ensco 84*	09/08/00	12/19/00	103	2472
JU	MO	991	*Pride Kansas*	02/03/00	03/27/00	54	1296
JU	MP	7	*Falcon Phoenix IV*	08/20/00	09/24/00	36	864
JU	MP	20	*Ensco 68*	12/05/00	12/31/00	27	648
JU	MP	20	*Marine 300*	10/27/00	10/30/00	4	96
JU	MP	61	*Pride Wyoming*	10/15/00	11/20/00	37	888
JU	MP	61	*Pride Wyoming*	11/01/00	11/14/00	14	336
JU	MP	61	*Pride Wyoming*	11/20/00	12/10/00	21	504
JU	MP	64	*Pool Ranger VII*	05/14/00	05/28/00	15	360
JU	MP	86	*R&B Falcon 251*	10/23/00	12/01/00	40	960
JU	MP	86	*R&B Falcon 251*	12/01/00	12/21/00	21	504
JU	MP	114	*Marine 200*	10/13/00	11/30/00	49	1176
JU	MP	114	*Marine 200*	10/13/00	11/19/00	38	912
JU	MP	131	*Ensco 98*	12/23/00	12/31/00	9	216
JU	MP	139	*Ensco 54*	08/16/00	08/30/00	15	360
JU	MP	150	*Ensco 68*	10/18/00	12/05/00	49	1176
JU	MP	151	*Noble Leonard Jones*	06/01/00	07/12/00	42	1008
JU	MP	159	*Pride Wyoming*	12/11/00	12/31/00	21	504
JU	MP	188	*Diamond Ocean Champion*	10/19/00	11/11/00	24	576
JU	MP	200	*Diamond Ocean Titan*	08/26/00	10/05/00	41	984
JU	MP	217	*Rowan-Alaska*	10/05/00	10/22/00	18	432
JU	MP	226	*Diamond Ocean Spur*	01/01/00	04/05/00	96	2304
JU	MP	226	*Marine 300*	09/10/00	10/27/00	48	1152
JU	MP	233	*Rowan-Alaska*	10/23/00	12/31/00	70	1680
JU	MP	241	*Ensco 60*	05/09/00	05/21/00	13	312
JU	MP	264	*Glomar Adriatic II*	01/01/00	01/14/00	14	336
JU	MP	264	*Rowan Paris*	03/04/00	04/10/00	38	912

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	MP	275	*Marine 303*	03/28/00	07/16/00	111	2664
JU	MP	277	*Glomar Main Pass IV*	01/01/00	01/10/00	10	240
JU	MP	277	*Glomar Main Pass IV*	09/05/00	10/25/00	51	1224
JU	MP	299	*Glomar Adriatic II*	01/18/00	01/21/00	4	96
JU	MP	312	*Chiles Tonala*	10/20/00	12/06/00	48	1152
JU	MU	726	*Diamond Ocean Tower*	08/04/00	12/18/00	137	3288
JU	MU	738	*Noble Sam Noble*	02/19/00	03/01/00	12	288
JU	PL	5	*Hercules 20*	01/01/00	03/19/00	79	1896
JU	PL	5	*Hercules 20*	08/11/00	10/27/00	78	1872
JU	PL	5	*Parker 20 J*	12/23/00	12/31/00	9	216
JU	PL	6	*Marine 225*	01/26/00	03/22/00	57	1368
JU	PL	11	*Diamond Ocean Spartan*	07/01/00	07/25/00	25	600
JU	PL	11	*Diamond Ocean Spartan*	07/25/00	09/14/00	52	1248
JU	PL	11	*Diamond Ocean Spartan*	09/14/00	10/14/00	31	744
JU	PL	15	*Hercules 20*	03/19/00	04/21/00	34	816
JU	SM	8	*Nobel Carl Norberg*	12/23/00	12/31/00	9	216
JU	SM	66	*Falcon 85*	05/26/00	07/07/00	43	1032
JU	SM	80	*Glomar High Island VIII*	04/14/00	05/12/00	29	696
JU	SM	80	*Glomar High Island VIII*	05/12/00	06/05/00	25	600
JU	SM	81	*Falcon 85*	01/07/00	01/21/00	15	360
JU	SM	105	*Falcon 85*	04/25/00	04/25/00	1	24
JU	SM	111	*Glomar High Island VIII*	06/06/00	07/23/00	48	1152
JU	SM	176	*Rowan Odessa*	08/28/00	09/12/00	16	384
JU	SM	235	*Hercules 14*	06/20/00	07/20/00	31	744
JU	SM	235	*Parker 14-J15*	10/31/00	11/19/00	20	480
JU	SM	236	*Pool Ranger V*	12/01/00	12/21/00	21	504
JU	SM	240	*Ensco 90*	01/16/00	02/07/00	23	552
JU	SM	253	*Pool 50*	11/12/00	12/04/00	23	552
JU	SM	255	*Sundowner Dolphin 106*	04/29/00	05/14/00	16	384
JU	SM	261	*Cliffs Drilling 153*	01/01/00	01/31/00	31	744
JU	SM	261	*Falcon 20*	01/31/00	02/05/00	6	144
JU	SM	261	*Falcon 20*	02/05/00	03/27/00	52	1248
JU	SM	261	*Hercules 11*	07/06/00	07/24/00	19	456
JU	SM	276	*Pride Alabama*	11/24/00	12/17/00	24	576
JU	SP	31	*Pride Kansas*	01/01/00	02/03/00	34	816
JU	SP	38	*Marine XVIII*	11/28/00	12/31/00	34	816
JU	SP	62	*Noble Leonard Jones*	07/13/00	07/28/00	16	384
JU	SS	27	*Parker 14-J15*	09/14/00	10/31/00	48	1152
JU	SS	32	*Ensco 93*	12/20/00	12/23/00	4	96
JU	SS	68	*Diamond Ocean Spartan*	05/22/00	06/05/00	15	360
JU	SS	68	*Pool 53*	01/01/00	01/15/00	15	360
JU	SS	76	*Rowan Texas*	07/09/00	08/06/00	29	696

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	SS	76	*Rowan Texas*	07/09/00	07/09/00	1	24
JU	SS	79	*Rowan Texas*	08/29/00	09/18/00	21	504
JU	SS	86	*Marine 300*	12/18/00	12/20/00	3	72
JU	SS	100	*Glomar High Island IV*	01/31/00	02/28/00	29	696
JU	SS	107	*Parker 20 J*	12/15/00	12/23/00	9	216
JU	SS	126	*Diamond Ocean Spartan*	03/01/00	04/26/00	57	1368
JU	SS	139	*Diamond Ocean Champion*	04/19/00	06/17/00	60	1440
JU	SS	139	*Falcon Phoenix III*	04/04/00	04/25/00	22	528
JU	SS	148	*Marine XVII*	05/28/00	06/10/00	14	336
JU	SS	207	*Rowan Gilbert Rowe*	09/25/00	11/09/00	46	1104
JU	SS	209	*Glomar High Island II*	07/12/00	10/16/00	97	2328
JU	SS	209	*Glomar High Island II*	11/20/00	12/31/00	42	1008
JU	SS	209	*Glomar High Island II*	11/21/00	12/05/00	15	360
JU	SS	246	*Chiles Tonala*	09/25/00	10/20/00	26	624
JU	SS	278	*Falcon 20*	01/01/00	01/09/00	9	216
JU	SS	283	*Pride Wyoming*	09/26/00	11/01/00	37	888
JU	SS	296	*Rowan Odessa*	06/01/00	07/28/00	58	1392
JU	SS	296	*Rowan Odessa*	07/28/00	08/15/00	19	456
JU	SS	313	*Ensco 69*	01/14/00	02/14/00	32	768
JU	SS	349	*Rowan Gorilla IV*	09/17/00	11/19/00	64	1536
JU	ST	26	*Falcon Phoenix III*	04/26/00	05/18/00	23	552
JU	ST	31	*Glomar High Island VIII*	01/01/00	01/13/00	13	312
JU	ST	31	*Glomar High Island VIII*	01/01/00	02/02/00	33	792
JU	ST	33	*Ensco 90*	11/05/00	12/10/00	36	864
JU	ST	67	*Ensco 94*	08/29/00	12/31/00	125	3000
JU	ST	72	*Falcon 85*	02/25/00	05/21/00	87	2088
JU	ST	139	*Rowan Charles Rowan*	01/31/00	06/15/00	137	3288
JU	ST	143	*Falcon Phoenix I*	01/01/00	01/11/00	11	264
JU	ST	162	*Glomar Main Pass IV*	01/01/00	01/31/00	31	744
JU	ST	176	*Ensco 94*	07/19/00	08/29/00	42	1008
JU	ST	204	*Glomar Main Pass I*	07/31/00	11/27/00	120	2880
JU	ST	204	*Glomar Main Pass I*	11/29/00	12/31/00	33	792
JU	ST	204	*Glomar Main Pass I*	12/31/00	12/31/00	1	24
JU	ST	212	*Marine 200*	02/04/00	03/22/00	48	1152
JU	ST	213	*Falcon 20*	01/09/00	02/02/00	25	600
JU	ST	213	*R&B Falcon 252*	08/27/00	09/22/00	27	648
JU	ST	238	*Marine III*	05/25/00	07/28/00	65	1560
JU	ST	250	*Marine III*	07/28/00	08/09/00	13	312
JU	ST	250	*Marine III*	07/28/00	08/16/00	20	480
JU	ST	254	*Ensco 68*	09/06/00	09/25/00	20	480
JU	ST	266	*R&B Falcon 252*	09/22/00	10/13/00	22	528
JU	VK	69	*Pride Kansas*	04/06/00	06/02/00	58	1392

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	VK	158	*Diamond Ocean Drake*	11/01/00	12/31/00	61	1464
JU	VK	205	*Falcon Phoenix I*	05/28/00	07/06/00	40	960
JU	VK	251	*Pride Kansas*	07/10/00	07/16/00	7	168
JU	VK	251	*Pride Texas*	03/13/00	04/06/00	25	600
JU	VK	252	*Pride Kansas*	07/20/00	08/15/00	27	648
JU	VK	384	*Falcon Phoenix III*	01/01/00	02/15/00	46	1104
JU	VK	385	*Falcon Phoenix III*	05/19/00	07/29/00	72	1728
JU	VK	475	*Falcon Phoenix I*	04/22/00	05/27/00	36	864
JU	VK	565	*Noble Johnnie Hoffman*	11/11/00	12/31/00	51	1224
JU	VR	47	*Glomar High Island I*	03/18/00	06/30/00	105	2520
JU	VR	47	*Rowan Juneau*	01/01/00	03/01/00	61	1464
JU	VR	56	*Cliffs Drilling 153*	02/21/00	05/18/00	88	2112
JU	VR	63	*Marine 201*	07/11/00	08/31/00	52	1248
JU	VR	88	*Ensco 54*	03/17/00	04/18/00	33	792
JU	VR	114	*Falcon 20*	06/01/00	06/19/00	19	456
JU	VR	130	*Pool 54*	01/01/00	02/10/00	41	984
JU	VR	144	*Marine 300*	03/13/00	04/29/00	48	1152
JU	VR	161	*Hercules 11*	01/13/00	02/03/00	22	528
JU	VR	161	*Hercules 11*	02/03/00	05/10/00	98	2352
JU	VR	161	*Pride Arkansas*	12/18/00	12/31/00	14	336
JU	VR	161	*Rowan Middletown*	02/22/00	07/21/00	151	3624
JU	VR	252	*Diamond Ocean Nugget*	02/11/00	03/19/00	38	912
JU	VR	253	*Rowan Cecil Provine*	01/01/00	03/24/00	84	2016
JU	VR	261	*Pride Texas*	12/07/00	12/31/00	25	600
JU	VR	263	*Pride Arkansas*	10/30/00	12/17/00	49	1176
JU	VR	267	*Marine XVIII*	02/13/00	03/12/00	29	696
JU	VR	309	*Noble Johnnie Hoffman*	01/01/00	01/05/00	5	120
JU	VR	320	*R & B Falcon F G Mcclintock*	12/11/00	12/31/00	21	504
JU	VR	326	*Ensco 51*	01/01/00	01/01/00	1	24
JU	VR	336	*Ensco 55*	01/01/00	02/19/00	50	1200
JU	VR	356	*Glomar Adriatic X*	11/27/00	12/31/00	35	840
JU	VR	356	*Rowan Louisiana*	01/01/00	02/15/00	46	1104
JU	VR	369	*Ensco 67*	09/28/00	10/21/00	24	576
JU	VR	375	*Ensco 67*	08/09/00	09/25/00	48	1152
JU	WC	19	*Noble Earl Fredrickson*	08/13/00	12/27/00	137	3288
JU	WC	28	*Diamond Ocean Titan*	01/01/00	03/05/00	65	1560
JU	WC	28	*Rowan Anchorage*	06/11/00	07/15/00	35	840
JU	WC	28	*Rowan Anchorage*	07/15/00	07/15/00	1	24
JU	WC	45	*Cliff Drilling 200*	06/06/00	06/13/00	8	192
JU	WC	48	*Noble Earl Fredrickson*	12/27/00	12/31/00	5	120
JU	WC	65	*Marine 303*	01/01/00	01/19/00	19	456
JU	WC	110	*Diamond Ocean Spur*	07/15/00	10/25/00	103	2472

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	WC	110	*Diamond Ocean Spur*	07/15/00	07/15/00	1	24
JU	WC	164	*Cliff Drilling 200*	05/02/00	06/04/00	34	816
JU	WC	170	*Noble Johnnie Hoffman*	03/01/00	04/05/00	36	864
JU	WC	170	*Noble Johnnie Hoffman*	06/09/00	10/21/00	135	3240
JU	WC	170	*Nobel Johnnie Hoffman*	06/11/00	06/11/00	1	24
JU	WC	192	*Marine XVII*	10/12/00	12/06/00	56	1344
JU	WC	201	*Marine XVI*	04/09/00	08/01/00	115	2760
JU	WC	248	*Marine XVI*	01/17/00	02/15/00	30	720
JU	WC	277	*Pride Louisiana*	07/12/00	07/18/00	7	168
JU	WC	297	*Hercules 15*	06/23/00	12/31/00	192	4608
JU	WC	297	*Parker Rig 15*	06/22/00	06/23/00	2	48
JU	WC	300	*Cliff Drilling 200*	01/01/00	01/15/00	15	360
JU	WC	300	*Cliff Drilling 200*	01/15/00	05/02/00	109	2616
JU	WC	367	*Pride Louisiana*	07/30/00	09/04/00	37	888
JU	WC	368	*Pool 50*	01/01/00	01/09/00	9	216
JU	WC	368	*Pride Louisiana*	07/20/00	07/28/00	9	216
JU	WC	370	*Marine 201*	10/16/00	12/05/00	51	1224
JU	WC	370	*Marine 201*	12/20/00	12/29/00	10	240
JU	WC	379	*Falcon 18*	05/14/00	06/17/00	35	840
JU	WC	379	*Falcon 18*	05/14/00	06/16/00	34	816
JU	WC	440	*Rowan Odessa*	11/06/00	11/29/00	24	576
JU	WC	492	*Marine 301*	07/30/00	09/30/00	63	1512
JU	WC	494	*Marine 201*	09/01/00	10/16/00	46	1104
JU	WC	498	*Glomar High Island I*	07/02/00	08/01/00	31	744
JU	WC	498	*Glomar High Island I*	08/01/00	09/10/00	41	984
JU	WC	515	*Glomar Adriatic III*	05/28/00	05/30/00	3	72
JU	WC	515	*Glomar Adriatic X*	05/30/00	10/26/00	150	3600
JU	WC	516	*Rowan-Alaska*	02/03/00	03/09/00	36	864
JU	WC	523	*Rowan Louisiana*	01/09/00	03/16/00	68	1632
JU	WC	526	*Rowan-Alaska*	03/09/00	06/07/00	91	2184
JU	WC	537	*Rowan Houston*	01/01/00	05/20/00	141	3384
JU	WC	598	*Rowan Louisiana*	07/21/00	08/17/00	28	672
JU	WC	598	*Rowan Louisiana*	08/18/00	09/22/00	36	864
JU	WC	613	*Glomar Adriatic IX*	01/01/00	02/01/00	32	768
JU	WC	613	*Rowan Halifax*	06/27/00	07/30/00	34	816
JU	WD	23	*Pool Ranger V*	08/12/00	10/29/00	79	1896
JU	WD	23	*Pool Ranger VII*	06/01/00	07/06/00	36	864
JU	WD	39	*Falcon Phoenix III*	07/30/00	09/05/00	38	912
JU	WD	58	*Diamond Ocean Crusader*	05/06/00	09/19/00	137	3288
JU	WD	58	*Diamond Ocean Crusader*	10/01/00	11/27/00	58	1392
JU	WD	59	*Diamond Ocean Crusader*	01/01/00	01/01/00	1	24
JU	WD	59	*Diamond Ocean Crusader*	04/25/00	05/04/00	10	240

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
JU	WD	59	*Marine 300*	11/01/00	12/11/00	41	984
JU	WD	59	*Marine XVIII*	09/19/00	11/28/00	71	1704
JU	WD	63	*Diamond Ocean Crusader*	01/02/00	01/20/00	19	456
JU	WD	98	*Diamond Ocean Crusader*	02/29/00	04/24/00	56	1344
JU	WD	109	*Noble Leonard Jones*	01/28/00	02/23/00	27	648
JU	WD	112	*Glomar Adriatic X*	01/01/00	03/08/00	68	1632
JU	WD	117	*Marine XV*	11/01/00	11/10/00	10	240
JU	WD	136	*Ensco 68*	01/01/00	01/16/00	16	384
JU	WD	137	*Rowan Gorilla IV*	06/19/00	06/26/00	8	192
JU	WD	137	*Rowan Gorilla IV*	07/03/00	09/13/00	73	1752
SS	AC	195	*Noble Max Smith*	07/23/00	08/25/00	34	816
SS	AC	627	*Noble Max Smith*	01/01/00	02/24/00	55	1320
SS	AC	627	*Noble Max Smith*	01/15/00	02/28/00	45	1080
SS	AT	8	*Diamond Ocean Quest*	11/28/00	11/30/00	3	72
SS	AT	63	*Diamond Ocean Star*	01/01/00	05/23/00	144	3456
SS	AT	113	*Transocean Marianas*	07/06/00	08/20/00	46	1104
SS	EB	201	*Diamond Ocean Saratoga*	11/10/00	12/31/00	52	1248
SS	EB	430	*Noble Max Smith*	04/09/00	05/10/00	32	768
SS	EB	599	*Ensco E7500*	12/01/00	12/31/00	31	744
SS	EB	602	*Diamond Ocean Star*	07/09/00	11/21/00	136	3264
SS	EB	602	*Noble Amos Runner*	01/01/00	01/16/00	16	384
SS	EB	643	*Diamond Ocean Quest*	12/21/00	12/31/00	11	264
SS	EB	832	*Noble Homer Ferrington*	12/13/00	12/31/00	19	456
SS	EB	945	*Marine 700*	11/25/00	12/31/00	37	888
SS	EC	345	*R&B C. Kirk Rhein, Jr.*	07/26/00	08/26/00	32	768
SS	EI	346	*Rowan Midland*	04/16/00	06/21/00	67	1608
SS	EI	397	*R&B C. Kirk Rhein, Jr.*	08/27/00	10/01/00	36	864
SS	EI	397	*R&B C. Kirk Rhein, Jr.*	10/01/00	11/11/00	42	1008
SS	EW	871	*Diamond Ocean Concord*	09/22/00	11/10/00	50	1200
SS	EW	871	*Diamond Ocean Concord*	11/10/00	12/31/00	52	1248
SS	EW	878	*Diamond Ocean Saratoga*	06/08/00	09/26/00	111	2664
SS	EW	965	*Diamond Ocean Endeavor*	01/01/00	04/24/00	115	2760
SS	EW	966	*Noble Homer Ferrington*	04/08/00	05/10/00	33	792
SS	EW	1010	*Noble Paul Romano*	07/03/00	07/29/00	27	648
SS	GB	73	*Noble Homer Ferrington*	03/14/00	04/07/00	25	600
SS	GB	74	*Ocean Ambassador*	01/16/00	01/31/00	16	384
SS	GB	158	*Diamond Ocean Valiant*	05/09/00	06/16/00	39	936
SS	GB	158	*Diamond Ocean Valiant*	06/23/00	07/09/00	17	408
SS	GB	215	*Diamond Ocean Valiant*	07/09/00	07/12/00	4	96
SS	GB	215	*Diamond Ocean Valiant*	12/16/00	12/31/00	16	384
SS	GB	215	*Noble Max Smith*	12/12/00	12/16/00	5	120

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
SS	GB	240	*Diamond Ocean Ambassador*	02/01/00	02/13/00	13	312
SS	GB	272	*Transocean 96*	11/28/00	12/31/00	34	816
SS	GB	297	*Noble Jim Thompson*	11/05/00	12/12/00	38	912
SS	GB	297	*Noble Jim Thompson*	12/12/00	12/31/00	20	480
SS	GB	303	*Diamond Ocean Valiant*	03/22/00	05/05/00	45	1080
SS	GB	344	*Glomar Arctic I*	08/28/00	09/28/00	32	768
SS	GB	344	*Glomar Arctic I*	09/29/00	12/19/00	82	1968
SS	GB	367	*Diamond Ocean Voyager*	11/08/00	11/08/00	1	24
SS	GB	367	*Diamond Ocean Voyager*	11/08/00	12/31/00	54	1296
SS	GB	385	*Glomar Arctic I*	01/01/00	05/05/00	126	3024
SS	GB	385	*Glomar Arctic I*	05/05/00	08/11/00	99	2376
SS	GB	562	*Noble Amos Runner*	08/10/00	09/26/00	48	1152
SS	GB	668	*Noble Amos Runner*	04/06/00	07/04/00	90	2160
SS	GB	668	*Noble Amos Runner*	09/27/00	11/16/00	51	1224
SS	GB	668	*Transocean Richardson*	12/01/00	12/31/00	31	744
SS	GB	754	*Diamond Ocean Valiant*	02/07/00	03/22/00	45	1080
SS	GB	782	*Diamond Ocean Victory*	03/25/00	04/26/00	33	792
SS	GB	782	*Diamond Ocean Victory*	04/26/00	05/12/00	17	408
SS	GB	782	*Diamond Ocean Victory*	05/12/00	05/26/00	15	360
SS	GB	782	*Diamond Ocean Victory*	05/26/00	06/01/00	7	168
SS	GB	782	*Diamond Ocean Victory*	06/01/00	06/05/00	5	120
SS	GB	782	*Diamond Ocean Victory*	06/05/00	07/03/00	29	696
SS	GB	782	*Diamond Ocean Victory*	07/03/00	07/16/00	14	336
SS	GB	782	*Diamond Ocean Victory*	07/16/00	08/11/00	27	648
SS	GB	782	*Diamond Ocean Victory*	08/11/00	09/01/00	22	528
SS	GC	7	*Borgny Dolphin*	09/08/00	10/01/00	24	576
SS	GC	90	*Rowan Midland*	06/23/00	08/12/00	51	1224
SS	GC	155	*Diamond Ocean Worker*	05/10/00	05/11/00	2	48
SS	GC	165	*Diamond Ocean Amercia*	05/12/00	08/29/00	110	2640
SS	GC	165	*Diamond Ocean America*	08/31/00	12/31/00	123	2952
SS	GC	237	*Falcon 100*	08/30/00	12/09/00	102	2448
SS	GC	288	*Diamond Ocean Star*	05/23/00	07/06/00	45	1080
SS	GC	297	*Attwood Hunter*	08/18/00	11/11/00	86	2064
SS	GC	338	*Noble Amos Runner*	11/19/00	12/31/00	43	1032
SS	GC	473	*Noble Paul Romano*	02/24/00	03/27/00	33	792
SS	GC	505	*Diamond Ocean Quest*	09/13/00	09/28/00	16	384
SS	GC	505	*Diamond Ocean Quest*	09/28/00	10/28/00	31	744
SS	GC	506	*Diamond Ocean Quest*	10/28/00	11/21/00	25	600
SS	GC	563	*Glomar Celtic Sea*	03/14/00	07/01/00	110	2640
SS	GC	563	*Glomar Celtic Sea*	04/01/00	11/07/00	221	5304
SS	GC	608	*Transocean Richardson*	03/13/00	09/20/00	192	4608

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
SS	GC	608	*Transocean Richardson*	09/20/00	11/29/00	71	1704
SS	GC	737	*Noble Homer Ferrington*	08/13/00	09/13/00	32	768
SS	GC	783	*Diamond Ocean Victory*	09/01/00	12/15/00	106	2544
SS	GI	111	*Transocean 96*	09/01/00	11/23/00	84	2016
SS	GI	116	*Transocean 96*	01/21/00	03/14/00	54	1296
SS	HI	154	*R&B C. Kirk Rhein, Jr.*	01/01/00	01/18/00	18	432
SS	HI	A 582	*Rowan Midland*	09/24/00	12/31/00	99	2376
SS	KC	199	*Noble Amos Runner*	07/05/00	08/10/00	37	888
SS	MC	68	*Diamond Ocean Saratoga*	05/08/00	06/04/00	28	672
SS	MC	248	*Diamond Ocean Quest*	01/01/00	03/23/00	83	1992
SS	MC	321	*Diamond Ocean Concord*	08/16/00	09/20/00	36	864
SS	MC	379	*Noble Amos Runner*	01/12/00	03/31/00	80	1920
SS	MC	401	*Diamond Ocean Lexington*	12/18/00	12/31/00	14	336
SS	MC	582	*Diamond Ocean Concord*	01/19/00	05/10/00	113	2712
SS	MC	595	*Noble Homer Ferrington*	10/14/00	12/09/00	57	1368
SS	MC	632	*Diamond Ocean Quest*	08/16/00	09/10/00	26	624
SS	MC	657	*Transocean Marianas*	01/04/00	02/28/00	56	1344
SS	MC	705	*Diamond Ocean Quest*	12/01/00	12/10/00	10	240
SS	MC	705	*Diamond Ocean Rover*	01/01/00	01/27/00	27	648
SS	MC	711	*Noble Max Smith*	03/04/00	04/05/00	33	792
SS	MC	711	*Noble Max Smith*	05/10/00	07/23/00	75	1800
SS	MC	711	*Noble Max Smith*	09/06/00	10/31/00	56	1344
SS	MC	727	*Transocean Marianas*	08/20/00	12/31/00	134	3216
SS	MC	727	*Transocean Marianas*	08/21/00	12/31/00	133	3192
SS	MC	764	*Noble Jim Thompson*	03/09/00	09/12/00	188	4512
SS	MC	773	*Noble Homer Ferrington*	05/14/00	07/09/00	57	1368
SS	MC	988	*Noble Paul Romano*	03/30/00	07/01/00	94	2256
SS	PI	167	*Diamond Ocean Worker*	07/14/00	08/11/00	29	696
SS	SP	90	*Diamond Ocean Lexington*	11/17/00	12/03/00	17	408
SS	SS	313	*Rowan Midland*	08/12/00	08/29/00	18	432
SS	ST	317	*Transocean Richardson*	08/23/00	11/29/00	99	2376
SS	VK	739	*Borgny Dolphin*	06/27/00	09/08/00	74	1776
SS	VK	740	*Diamond Ocean Lexington*	09/11/00	10/11/00	31	744
SS	VR	408	*Diamond Ocean Ambassador*	07/11/00	11/23/00	136	3264
SS	VR	408	*Rowan Midland*	01/01/00	04/16/00	107	2568
SU	EI	39	*Attwood Richmond*	01/02/00	03/11/00	70	1680
SU	EI	39	*Attwood Richmond*	03/11/00	04/05/00	26	624

Table B-1. Vessel Rig Activity (Continued).

Rig Type*	Surface Area Code	Surface Block Number	Rig Name	Rig Move on Date	Rig Move off Date	Days	Hours
SU	EI	60	*R&B Falcon 75*	11/10/00	12/27/00	48	1152
SU	EI	60	*R&B Falcon 75*	12/27/00	12/31/00	5	120
SU	SS	32	*Noble Joe Alford*	06/11/00	09/11/00	93	2232
SU	WC	57	*Attwood Richmond*	10/13/00	11/13/00	32	768

*DS = Drill Ship
JU = Jack up
SS = Semisubmersible
SU = Submersible

Table B-2. Drill Ship Emission Factors.

Activity Data		
	Ave. HP	Ave. kW
Prime	2,500.00	1,864.25
Pumps	1,600.00	1,193.12
Drawworks	3,000.00	2,237.10
Total	7,100.00	5,294.47
Operating Load		75%

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	intercept (B)	Coefficient (A)	Average kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	5,294.47	1.40	3.08
NO_x	10.64	1.50	10.45	0.13	5,294.47	56.35	124.23
SO_2*	1.79	N/A	0.00	2.00	5,294.47	9.48	20.90
CO	1.12	1.00	0.00	0.84	5,294.47	5.91	13.04
VOC	0.10	1.50	0.00	0.07	5,294.47	0.54	1.20
CO_2	707.40	1.00	648.60	44.10	5,294.47	3,745.31	8,256.91

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table B-3. Jackup Rig Emission Factors.

Activity Data		
	Ave. HP	Ave. kW
Prime	1,660.00	1,237.86
Pumps	1,600.00	1,193.12
Drawworks	2,000.00	1,491.40
Total	5,260.00	3,922.38
Operating Load		75%

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	intercept (B)	Coefficient (A)	Average kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	3,922.38	1.04	2.28
NO_x	10.64	1.50	10.45	0.13	3,922.38	41.75	92.03
SO_2*	1.79	N/A	0.00	2.00	3,922.38	7.02	15.48
CO	1.12	1.00	0.00	0.84	3,922.38	4.38	9.66
VOC	0.10	1.50	0.00	0.07	3,922.38	0.40	0.89
CO_2	707.40	1.00	648.60	44.10	3,922.38	2,774.69	6,117.09

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table B-4. Semisubmersible Rig Emission Factors.

Activity Data		
	Ave. HP	Ave. kW
Prime	2,034.00	1,516.75
Pumps	1,600.00	1,193.12
Drawworks	3,000.00	2,237.10
Total	6,634.00	4,946.97
Operating Load		75%

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	intercept (B)	Coefficient (A)	Average kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	4,946.97	1.31	2.88
NO_x	10.64	1.50	10.45	0.13	4,946.97	52.65	116.07
SO_2*	1.79	N/A	0.00	2.00	4,946.97	8.86	19.52
CO	1.12	1.00	0.00	0.84	4,946.97	5.53	12.18
VOC	0.10	1.50	0.00	0.07	4,946.97	0.51	1.12
CO_2	707.40	1.00	648.60	44.10	4,946.97	3,499.49	7,714.97

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table B-5. Submersible Rig Emission Factors.

Activity Data		
	Ave. HP	Ave. kW
Prime	2,034.00	1,516.75
Pumps	1,600.00	1,193.12
Drawworks	3,000.00	2,237.10
Total	6,634.00	4,946.97

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Average kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	4,946.97	1.31	2.88
NO_x	10.64	1.50	10.45	0.13	4,946.97	52.65	116.07
SO_2*	1.79	N/A	0.00	2.00	4,946.97	8.86	19.52
CO	1.12	1.00	0.00	0.84	4,946.97	5.53	12.18
VOC	0.10	1.50	0.00	0.07	4,946.97	0.51	1.12
CO_2	707.40	1.00	648.60	44.10	4,946.97	3,499.49	7,714.97

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table B-6. Emission Estimates for Exploratory Drill Ship Operations (tons/year).

Pollutant	Drill Ship Type*				Total
	Drill	Jackup	Semi	Submersible	
PM	52.95	412.16	202.33	9.47	676.92
NO_x	2,133.19	16,604.32	8,151.01	381.64	27,270.17
SO_2**	358.81	2,792.94	1,371.05	64.19	4,586.99
CO	223.90	1,742.78	855.53	40.06	2,862.27
VOC	20.58	160.21	78.65	3.68	263.13
CO_2	141,787.59	1,103,645.06	541,776.34	25,366.83	1,812,575.83

* Hours of operation, Drill 34,344, Jackup 360,840, Semi 140,448, Submersible 6,576.
** For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717* fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

References

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APPENDIX C

SUPPORT VESSELS

Support vessels include several different types of vessels that operate at various power levels throughout a typical work day. The number of each of these types of vessels operating in the offshore Gulf areas in 1992 was provided in the GMAQS (U.S. DOI, MMS 1995). It should be noted that the vessel numbers used in the 1995 report were derived from a survey which had a response rate of 64 percent, such that, the actual number of support vessels operating in the Gulf may be larger than numbers reported in the GMAQS.

To determine the number of support vessels operating in 2000, it was assumed that the vessel population varied proportionally with the number of active platforms in the Gulf. Since 1992, the number of platforms has increased 17% (U.S. DOI, MMS 1995, Coe et al. 2003), therefore, the 1992 support vessel fleet population was increased 17% to represent the fleet size in 2000 (see Table C-1). Note that this increased number of platforms in the Gulf is not related to the number of platforms that reported in the Gulfwide Study vs. the GMAQS.

The GMAQS also provided an estimate of the average number of hours worked for all vessels (21 hours/day), the average horsepower of each vessel type, the percentage of time each vessel spent in a specific operating mode (hoteling, maneuvering, and cruising), and the percent of total power used in each mode. It is assumed that these numbers have not changed significantly since 1992. For each vessel type, each power setting is associated with different engine load values. The aggregated load factor was calculated using the following equation:

Aggregated Operating Load Factor = (10% of power used) (% of time hoteling) +
(55% of power used) (% of time maneuvering) +
(100% of power used) (% of time cruising)

These calculations are shown in Table C-2.

Emission factors for each type of support vessel were derived using the EPA marine diesel emission equation:

$$E\ (\text{g/kW-hr}) = A * (\text{Load Factors})^{-x} + B$$

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables C-3, C-4, C-5, and C-6 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For SO_2, it is necessary to first calculate *Fuel Consumption* using the following equation:

$$\text{Fuels Consumption (g/kW-hr)} = 14.12/(\text{fractional load}) + 205.717$$

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A* (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

The equations provided power-based emission factors that are applied to the average horsepower of the vessel and the total hours of operations to estimate emissions. Emission estimates for each type of support vessel are noted in Table C-7.

Table C-1. 2000 Data on Support Vessels.[a]

Vessel Type	1992 No of Vessels	1992 Average HP	1992 Operating Load	2000 Est No of Vessels	2000 Average HP	2000 Load Factor
Crew Boats	88	480	87%	103	480	87%
Supply Boats	326	868	55%	382	868	55%
Tugs	60	2,234	54%	70	2,234	54%
Barges	27	308	55%	32	308	55%
Total	501	3,890		588	3,890	

[a] Note: 2000 data derived by calculating the percent increase (17.21%) between 1992 and 2000 of oil platforms and applying to the 1992 numbers.

Table C-2. Determination of Load Factor for Supply Boats in the Gulf of Mexico.

Operation Mode	Operating Load	% Time at each Operation Mode				Weighted Operating Load **			
		Crew	Supply	Tugs*	Barges*	Crew	Supply	Tugs*	Barges*
Hoteling	10%	10%	45%	33%	50%	1%	4.5%	3.3%	5%
Maneuvering	55%	10%	10%	33%	0%	5.5%	5.5%	18.2%	0%
Cruising	100%	80%	45%	33%	50%	80%	45%	33%	50%
Aggregated Weighted Load ***						86.5%	55%	54.4%	55%

* Tugs and barges with diesel engines.
** Weighted Operating Load = Operating load x time at each operation model.
***Aggregated Operating Load Factor = Sum of weighted operating load.

Table C-3. Activity Data and Emission Factors for Crew Boats.

Summary Data for Crew Boats				
Vessels	Operating Load	Avg HP	Avg kW	Total Engine Hrs
103	86.5%	480	357.936	790,973.8941

Emission Factors for Crew Boats							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.2624	1.5	0.2551	0.0059	357.9	0.09	0.21
NO_x	10.6056	1.5	10.4496	0.1255	357.9	3.80	8.37
SO_2*	1.7702	N/A	0	1.998	357.9	0.63	1.40
CO	0.9686	1	0	0.8378	357.9	0.35	0.76
VOC	0.0829	1.5	0	0.0667	357.9	0.03	0.07
CO_2	699.5827	1	648.6	44.1	357.9	250.41	552.0

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table C-4. Activity Data and Emission Factors for Supply Vessels.

Summary Data for Supply Vessels				
Vessels	Operating Load	Avg HP	Avg kW	Total Engine Hrs
382	55%	868	647.2676	2,930,198.744

Emission Factors for Supply Vessels							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.2696	1.5	0.2551	0.0059	647.3	0.17	0.38
NO_x	10.7573	1.5	10.4496	0.1255	647.3	6.96	15.35
SO_2*	1.8449	N/A	0	1.998	647.3	1.19	2.63
CO	1.5233	1	0	0.8378	647.3	0.99	2.17
VOC	0.1635	1.5	0	0.0667	647.3	0.11	0.23
CO_2	728.7818	1	648.6	44.1	647.3	471.72	1,039.9

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table C-5. Activity Data and Emission Factors for Tugs with Diesel Engines.

Summary Data for Tugs with Diesel Engines				
Vessels	Operating Load	Avg HP	Avg kW	Total Engine Hrs
70	54.4%	2234	1,665.8938	539,300.4

Emission Factors for Tugs with Diesel Engines							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.2698	1.5	0.2551	0.0059	1665.9	0.45	0.99
NO_x	10.7620	1.5	10.4496	0.1255	1665.9	17.93	39.52
SO_2*	1.8470	N/A	0	1.998	1665.9	3.08	6.78
CO	1.5387	1	0	0.8378	1665.9	2.56	5.65
VOC	0.1660	1.5	0	0.0667	1665.9	0.28	0.61
CO_2	729.5917	1	648.6	44.1	1665.9	1215.42	2,679.5

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table C-6. Activity Data and Emission Factors for Barges with Diesel Engines.

Summary Data for Barges with Diesel Engines				
Vessels	Operating Load	Avg HP	Avg kW	Total Engine Hrs
32	55%	308	229.6756	242,685

Emission Factors for Barges with Diesel Engines							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.2696	1.5	0.2551	0.0059	229.7	0.06	0.14
NO_x	10.7573	1.5	10.4496	0.1255	229.7	2.47	5.45
SO_2*	1.8449	N/A	0	1.998	229.7	0.42	0.93
CO	1.5233	1	0	0.8378	229.7	0.35	0.77
VOC	0.1635	1.5	0	0.0667	229.7	0.04	0.08
CO_2	728.7818	1	648.6	44.1	229.7	167.38	369.0

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table C-7. Summary of Emission Estimates for Support Vessels (tons/year).

Pollutant	Crew Boats	Supply boats	Tugs	Barges	Totals
PM	81.90	563.56	267.17	16.56	929.20
NO_x	3,309.81	22,489.68	10,657.83	660.94	37,118.26
SO_2	552.44	3,857.02	1,829.10	113.35	6,351.91
CO	302.27	3,184.63	1,523.77	93.59	5,104.26
VOC	25.87	341.87	164.40	10.05	542.19
CO_2	218,326.46	1,523,625.68	722,533.11	44,777.05	2,509,262.29

References

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APPENDIX D

SUPPORT HELICOPTERS

Helicopter activity data for 2000 were obtained from the *Helicopter Safety Advisory Conference's (HSAC) Gulf of Mexico Offshore Helicopter Operations and Safety Review* (HSAC 2001). The activity data were disaggregated into single engine, twin-engine, and heavy twin engine helicopters providing estimates for the number of helicopter trips taken and the average duration of a trip (see Table D-1). The average trip length was approximately 16 minutes that equated to a landing and take-off (LTO) cycle consisting of 2 minutes for takeoff, 7 minutes for climbout, 7 minutes for approach, and 20 minutes in idle.

The helicopter emission factors used in this inventory were derived from the report *Air Quality Management Plan, 1991 Revision, Final Technical Report III-G, 1987 Aircraft Emission Inventory in the South Coast Air Basin* (developed by the South Coast Air Quality Management District), the U.S. EPA's *Procedures for Emission Inventory Preparation Volume IV: Mobile Sources* (EPA 1992), data from the Allison helicopter engine manufacturer (Allison 2002), and the Department of the Navy's *Environmental Assessments* (Department of the Navy 1999). These emission factors are compiled in Tables D-1, D-2, and D-3. The emission factors were disaggregated into the helicopter types used in HSAC's activity data. The LTO emission factors for each helicopter type were averaged to obtain the aggregated emission factors used in this study. The data obtained from the military were not included in the average emission factor for two reasons. First, some of the emission factors were more than an order of magnitude different from the factors obtained from other data sources and a credible explanation for the difference could not be provided. Second, most of the helicopters used to support oil platform activities are commercial not military helicopters.

The emission test data were converted to LTO-based emission factors by weighting the lb/min test results by the amount of minutes the helicopter spent in each mode as noted in the following equation:

$$EF_{LTO} = \sum TD_i \times P_i$$

where

EF_{LTO} = LTO-Based emission factor (lb/LTO)

TD_i = Test data for Mode i (lb/min)
i = Mode (i.e., take off, climbout, approach and idle)
P_i = Period helicopter is in mode (minutes/LTO)

The LTO-based emission factors were averaged to get a representative factor.

The developed emission factors were applied to HSAC's activity data to estimate emissions as noted in the following example.

Example Calculation

Single-engine helicopter VOC estimate:

Emission Estimate	= Emission Factor x LTO
VOC Emission Estimate	= 0.808 lb VOC/LTO x 922,597 LTOs
	= 745, 458 lbs VOC
	= 372 tons VOC

Emission estimates for each helicopter type are provided in Table D-4.

Table D-1. Single-Engine Helicopter Emission Factors.

Helicopter	Engine	VOC (lb/LTO)	CO (lb/LTO)	NO_x (lb/LTO)	SO_2 (lb/LTO)
	Allison 250-C40B	0.971	4.465	0.851	
	Allison 250-C20S	0.310	2.437	0.426	
Bell UH-1, AH-1	T53-L-11D	3.773	5.391	1.752	0.187*
Bell 206 L3	Allison 250 C30P	0.204	1.400	0.190	
MBB B0105CBS	Allison C20B	0.398	2.800	0.380	
Bell 206 B3	Allison 250 C20J	0.204	1.400	0.190	
Aerospatiale AS355	Allison C20B	0.398	2.800	0.380	
Bell 206	Allison 250 C28	0.204	1.400	0.190	
	Average single	0.808	2.762	0.545	0.187

* SO_2 data for single-engine helicopter was only available for Bell UH-1/AH-1 helipcoter equipped with T53-L-11D engines.

D-2. Twin-Engine Helicopter Emission Factors.

Helicopter Model	T58-GE-8F	T58-GE-16	T58-GE-5	
Mode	VOC (lb/min)	VOC (lb/min)	VOC (lb/min)	Average
Takeoff	0.01	0.044	0.027	
Climbout	0.021	0.016	0.022	
Approach	0.017	0.008	0.022	
Idle	0.557	0.199	0.418	
EF/LTO	11.484	4.348	8.82	8.217

Helicopter Model	T58-GE-8F	T58-GE-16	T58-GE-5	
Mode	CO (lb/min)	CO (lb/min)	CO (lb/min)	Average
Takeoff	0.237	0.263	0.250	
Climbout	0.335	0.283	0.167	
Approach	0.295	0.318	0.167	
Idle	0.785	0.699	0.751	
EF/LTO	21.688	19.832	18.687	20.069

Helicopter Model	T58-GE-8F	T58-GE-16	T58-GE-5	
Mode	NO_x (lb/min)	NO_x (lb/min)	NO_x (lb/min)	Average
Takeoff	0.143	0.394	0.269	
Climbout	0.087	0.246	0.213	
Approach	0.098	0.172	0.213	
Idle	0.006	0.015	0.007	
EF/LTO	2.174	5.225	4.621	4.007

Helicopter Model	T58-GE-8F	T58-GE-16	T58-GE-5	
Mode	SO_2 (lb/min)	SO_2 (lb/min)	SO_2 (lb/min)	Average
Takeoff	0.014	0.018	0.016	
Climbout	0.010	0.014	0.016	
Approach	0.011	0.012	0.016	
Idle	0.002	0.003	0.002	
EF/LTO	0.278	0.334	0.368	0.327

D-2. Twin-Engine Helicopter Emission Factors (Continued).

Helicopter Model	T58-GE-5	
Mode	PM*	Average
Takeoff		
Climbout	0.027	
Approach	0.027	
Idle	0.003	
EF/LTO	0.492	0.492

* LTO emission factor based on available data for climb out approach and idle, note there were no values for take off.

D-3. Heavy Twin-Engine Helicopter Emission Factors.

Helicopter Model*	Mode	Power Setting	Fuel Flow (lb/min)	VOC (lb/1000 lb fuel)	CO (lb/1000 lb fuel)	NO_x (lb/1000 lb fuel)	SO_2 (lb/1000 lb fuel)	VOC (lb/min)	CO (lb/min)	NO_x (lb/min)	SO_2 (lb/min)
Sikorsky H-53 Sea Stallion/Super Stallion (3 engine)	Takeoff		33.42	0.18	1.47	10.83	0.54	0.018	0.147	1.086	0.054
	Climbout	Military	31.93	0.272	1.29	9.99	0.54	0.026	0.124	0.957	0.052
	Approach	0.8	24.88	0.126	2.1	8.09	0.54	0.009	0.157	0.604	0.040
	Idle	Idle	4.48	23.64	74.33	2.12	0.54	0.318	0.999	0.028	0.007
							lb/LTO	6.712	22.812	17.399	1.098

*Assumption: 3 engine helicopter approximates a heavy twin helicopter.

Table D-4. Summary of Helicopter Activity and Emissions Data.

Year 2000	Single	Twin	Heavy Twin	Total
Helicopters	385	182	15	582
LTOs	922,597	436,137	35,945	1,394,679

Emission Factors						
Type	VOC (lb/LTO)	CO (lb/LTO)	NO_x (lb/LTO)	SO_2 (lb/LTO)	PM_{10} (lb/LTO)	CO_2 (lb/LTO)*
Single	0.808	2.762	0.545	0.187		128.46
Twin	8.217	20.069	4.007	0.327	0.492	263.22
Heavy Twin	6.712	22.812	17.399	1.098		589.22
Emissions						
Type	VOC (tons/year)	CO (tons/year)	NOx (tons/year)	SO_2 (tons/year)	PM_{10} (tons/year)	CO_2 (tons/year)
Single	372.729	1,273.972	251.351	86.113		64,429.381
Twin	1,791.868	4,376.406	873.755	71.254	107.284	55,621.681
Heavy Twin	120.633	409.991	312.713	19.733		10,025.510
Total	2,285.220	6,060.370	1,437.819	177.117	107.284	130,076.572

* Note CO_2 emission factors were was derived by assuming that almost all carbon in the fuel is emitted as CO_2 and helicopter fuel is 87% carbon.

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APPENDIX E

PIPELAYING OPERATIONS

It is estimated in the GMAQS that 5 boats can lay 300 feet of pipe in a 24-hour period, such that it takes a total of 0.4 hours, or 24 minutes, to lay one foot of pipe (see Table E-1).

A load factor of 75 percent was assumed based on data provided in the GMAQS (U.S. DOI, MMS 1995). An average horsepower rating of 1,200 for all types of pipelaying vessels was provided in the GMAQS. It was assumed that this value would not change significantly in 2000. The load factor was used in the EPAs marine diesel emission factor equation (EPA 2000):

E (g/kW-hr) = A * (Load Factors) $^{-x}$ +B

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables E-2 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For $SO_{2,}$ it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A * (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

The developed emissions factors were applied to the average horsepower and total time to lay 1 foot of pipe to derive an emission factor that could be applied to the total length of pipe repaired or replaced.

GIS data provided by MMS listed the length of pipe constructed in 2000 for all of the offshore lease blocks (Froomer 2002). By applying the pipe length emission factor to the MMS data set, total emissions were calculated for each segment, and then summed for the Gulf of Mexico (see Table E-3).

Table E-1. Determination of Time to Lay One Foot of Pipe.

Boats*	Feet per Day	Operating Hrs per Day	Amount of Pipe per Hour (ft)	No. of Hours per Foot per Vessel	No. of Hours per Foot of Pipe
5	300	24	12.5	0.08	0.4

*Note: Number of boats was previously 6 and included 1 supply vessel, which has already been accounted for in the support vessel calculations and was therefore removed from the pipelaying calculation.

Table E-2. Activity Data and Emission Factors for Pipelaying Vessels (per foot of pipe).

Summary Data for Pipelaying Vessels			
Operating Load	Ave. HP	Ave. kW	Total Hrs per Foot
75%	1200	894.84	0.4

Emission Factors for Pipelaying Vessels (per foot of pipe)								
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	lbs/hr	Hrs/ft	Emission Factor (lbs/ft)
PM	0.26	1.50	0.26	0.01	894.84	0.52	0.40	0.21
NO_x	10.64	1.50	10.45	0.13	894.84	21.00	0.40	8.40
SO_2*	1.79	N/A	0.00	2.00	894.84	3.53	0.40	1.41
CO	1.12	1.00	0.00	0.84	894.84	2.20	0.40	0.88
VOC	0.10	1.50	0.00	0.07	894.84	0.20	0.40	0.08
CO_2	707.40	1.00	648.60	44.10	894.84	1,395.53	0.40	558.21

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table E-3. Allocation of Pollutant by Segment Number.

Pollutant		PM	NO_x	SO_2	CO	VOC	CO_2
Pollutant per foot of pipe (tons/ft)		0.000104	0.0042	0.0007063	0.00044	4.1E-05	0.2791067
Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
5475	6000	0.63	25.19	4.24	2.64	0.24	1674.64
10242	12731	1.33	53.46	8.99	5.61	0.52	3553.31
10243	12731	1.33	53.46	8.99	5.61	0.52	3553.31
11874	83712	8.73	351.52	59.13	36.90	3.39	23364.58
11875	87321	9.10	366.67	61.68	38.49	3.54	24371.88
11876	88963	9.27	373.57	62.84	39.21	3.60	24830.17
11877	12185	1.27	51.17	8.61	5.37	0.49	3400.91
11903	454203	47.34	1907.27	320.81	200.19	18.40	126771.10
11952	723354	75.40	3037.48	510.92	318.81	29.31	201892.94
12048	24579	2.56	103.21	17.36	10.83	1.00	6860.16
12050	5752	0.60	24.15	4.06	2.54	0.23	1605.42
12133	13235	1.38	55.58	9.35	5.83	0.54	3693.98
12222	32702	3.41	137.32	23.10	14.41	1.32	9127.35
12280	44393	4.63	186.41	31.36	19.57	1.80	12390.38
12320	1861	0.19	7.81	1.31	0.82	0.08	519.42
12321	1861	0.19	7.81	1.31	0.82	0.08	519.42
12349	3667	0.38	15.40	2.59	1.62	0.15	1023.48
12350	17715	1.85	74.39	12.51	7.81	0.72	4944.37
12351	17722	1.85	74.42	12.52	7.81	0.72	4946.33
12354	12669	1.32	53.20	8.95	5.58	0.51	3536.00
12355	9724	1.01	40.83	6.87	4.29	0.39	2714.03
12356	9726	1.01	40.84	6.87	4.29	0.39	2714.59
12357	3555	0.37	14.93	2.51	1.57	0.14	992.22
12358	3555	0.37	14.93	2.51	1.57	0.14	992.22
12383	12402	1.29	52.08	8.76	5.47	0.50	3461.48
12385	5014	0.52	21.05	3.54	2.21	0.20	1399.44

Table E-3. Allocation of Pollutant by Segment Number (Continued).

Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
12386	13779	1.44	57.86	9.73	6.07	0.56	3845.81
12388	14178	1.48	59.54	10.01	6.25	0.57	3957.17
12392	354	0.04	1.49	0.25	0.16	0.01	98.80
12394	13639	1.42	57.27	9.63	6.01	0.55	3806.74
12395	24305	2.53	102.06	17.17	10.71	0.98	6783.69
12397	7982	0.83	33.52	5.64	3.52	0.32	2227.83
12411	11827	1.23	49.66	8.35	5.21	0.48	3300.99
12415	3025	0.32	12.70	2.14	1.33	0.12	844.30
12416	3025	0.32	12.70	2.14	1.33	0.12	844.30
12418	4296	0.45	18.04	3.03	1.89	0.17	1199.04
12419	4296	0.45	18.04	3.03	1.89	0.17	1199.04
12427	4579	0.48	19.23	3.23	2.02	0.19	1278.03
12428	36275	3.78	152.32	25.62	15.99	1.47	10124.60
12429	36277	3.78	152.33	25.62	15.99	1.47	10125.15
12431	3461	0.36	14.53	2.44	1.53	0.14	965.99
12436	18134	1.89	76.15	12.81	7.99	0.73	5061.32
12437	22013	2.29	92.44	15.55	9.70	0.89	6143.98
12445	9663	1.01	40.58	6.83	4.26	0.39	2697.01
12448	11102	1.16	46.62	7.84	4.89	0.45	3098.64
12450	45941	4.79	192.91	32.45	20.25	1.86	12822.44
12451	17051	1.78	71.60	12.04	7.52	0.69	4759.05
12455	5005	0.52	21.02	3.54	2.21	0.20	1396.93
12458	3951	0.41	16.59	2.79	1.74	0.16	1102.75
12459	3952	0.41	16.60	2.79	1.74	0.16	1103.03
12461	17074	1.78	71.70	12.06	7.53	0.69	4765.47
12462	20811	2.17	87.39	14.70	9.17	0.84	5808.49
12469	9181	0.96	38.55	6.48	4.05	0.37	2562.48
12471	5547	0.58	23.29	3.92	2.44	0.22	1548.20
12472	2227	0.23	9.35	1.57	0.98	0.09	621.57
12477	16731	1.74	70.26	11.82	7.37	0.68	4669.73
12478	5046	0.53	21.19	3.56	2.22	0.20	1408.37

Table E-3. Allocation of Pollutant by Segment Number (Continued).

Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
12480	3929	0.41	16.50	2.78	1.73	0.16	1096.61
12481	4788	0.50	20.11	3.38	2.11	0.19	1336.36
12483	5023	0.52	21.09	3.55	2.21	0.20	1401.95
12484	5024	0.52	21.10	3.55	2.21	0.20	1402.23
12485	5021	0.52	21.08	3.55	2.21	0.20	1401.39
12488	8307	0.87	34.88	5.87	3.66	0.34	2318.54
12489	2320	0.24	9.74	1.64	1.02	0.09	647.53
12492	7940	0.83	33.34	5.61	3.50	0.32	2216.11
12502	20262	2.11	85.08	14.31	8.93	0.82	5655.26
12503	6470	0.67	27.17	4.57	2.85	0.26	1805.82
12507	1000	0.10	4.20	0.71	0.44	0.04	279.11
12513	29914	3.12	125.61	21.13	13.18	1.21	8349.20
12515	5031	0.52	21.13	3.55	2.22	0.20	1404.19
12517	4282	0.45	17.98	3.02	1.89	0.17	1195.13
12519	7783	0.81	32.68	5.50	3.43	0.32	2172.29
12533	24843	2.59	104.32	17.55	10.95	1.01	6933.85
12534	24697	2.57	103.71	17.44	10.89	1.00	6893.10
12536	5298	0.55	22.25	3.74	2.34	0.21	1478.71
12544	1909	0.20	8.02	1.35	0.84	0.08	532.81
12545	5092	0.53	21.38	3.60	2.24	0.21	1421.21
12546	11070	1.15	46.48	7.82	4.88	0.45	3089.71
12553	32851	3.42	137.95	23.20	14.48	1.33	9168.93
12559	4062	0.42	17.06	2.87	1.79	0.16	1133.73
12563	4510	0.47	18.94	3.19	1.99	0.18	1258.77
12564	4163	0.43	17.48	2.94	1.83	0.17	1161.92
12565	4163	0.43	17.48	2.94	1.83	0.17	1161.92
12572	7253	0.76	30.46	5.12	3.20	0.29	2024.36
12574	36932	3.85	155.08	26.09	16.28	1.50	10307.97
12575	2844	0.30	11.94	2.01	1.25	0.12	793.78
12576	22997	2.40	96.57	16.24	10.14	0.93	6418.62
12582	16367	1.71	68.73	11.56	7.21	0.66	4568.14

Table E-3. Allocation of Pollutant by Segment Number (Continued).

Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
12639	6241	0.65	26.21	4.41	2.75	0.25	1741.90
12640	8488	0.88	35.64	6.00	3.74	0.34	2369.06
12641	1864	0.19	7.83	1.32	0.82	0.08	520.25
12662	7009	0.73	29.43	4.95	3.09	0.28	1956.26
12693	11626	1.21	48.82	8.21	5.12	0.47	3244.89
12530	56730	5.91	238.22	40.07	25.00	2.30	15833.72
12531	23739	2.47	99.68	16.77	10.46	0.96	6625.71
12532	23798	2.48	99.93	16.81	10.49	0.96	6642.18
12549	7752	0.81	32.55	5.48	3.42	0.31	2163.64
12550	7752	0.81	32.55	5.48	3.42	0.31	2163.64
12651	37966	3.96	159.43	26.82	16.73	1.54	10596.56
12490	26750	2.79	112.33	18.89	11.79	1.08	7466.10
12491	26755	2.79	112.35	18.90	11.79	1.08	7467.50
12542	32	0.00	0.13	0.02	0.01	0.00	8.93
12552	861	0.09	3.62	0.61	0.38	0.03	240.31
12695	12153	1.27	51.03	8.58	5.36	0.49	3391.98
12765	11439	1.19	48.03	8.08	5.04	0.46	3192.70
12253	14766	1.54	62.00	10.43	6.51	0.60	4121.29
12420	13786	1.44	57.89	9.74	6.08	0.56	3847.76
12338	8052	0.84	33.81	5.69	3.55	0.33	2247.37
12391	5036	0.52	21.15	3.56	2.22	0.20	1405.58
12396	9392	0.98	39.44	6.63	4.14	0.38	2621.37
12426	4621	0.48	19.40	3.26	2.04	0.19	1289.75
12433	4240	0.44	17.80	2.99	1.87	0.17	1183.41
12446	5776	0.60	24.25	4.08	2.55	0.23	1612.12
12604	2651	0.28	11.13	1.87	1.17	0.11	739.91
12605	2649	0.28	11.12	1.87	1.17	0.11	739.35
12652	5013	0.52	21.05	3.54	2.21	0.20	1399.16
12406	9974	1.04	41.88	7.04	4.40	0.40	2783.81
12409	9974	1.04	41.88	7.04	4.40	0.40	2783.81
12508	33783	3.52	141.86	23.86	14.89	1.37	9429.06

Table E-3. Allocation of Pollutant by Segment Number (Continued).

Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
12742	15764	1.64	66.20	11.13	6.95	0.64	4399.84
12743	3135	0.33	13.16	2.21	1.38	0.13	875.00
12405	117990	12.30	495.46	83.34	52.00	4.78	32931.80
12626	76180	7.94	319.89	53.81	33.58	3.09	21262.35
12650	99	0.01	0.42	0.07	0.04	0.00	27.63
12631	4201	0.44	17.64	2.97	1.85	0.17	1172.53
12402	13009	1.36	54.63	9.19	5.73	0.53	3630.90
12101	4838	0.50	20.32	3.42	2.13	0.20	1350.32
12467	5480	0.57	23.01	3.87	2.42	0.22	1529.50
12468	5480	0.57	23.01	3.87	2.42	0.22	1529.50
12778	29269	3.05	122.91	20.67	12.90	1.19	8169.17
12506	59077	6.16	248.07	41.73	26.04	2.39	16488.79
12612	18024	1.88	75.69	12.73	7.94	0.73	5030.62
12613	18024	1.88	75.69	12.73	7.94	0.73	5030.62
12620	15731	1.64	66.06	11.11	6.93	0.64	4390.63
12750	10851	1.13	45.57	7.66	4.78	0.44	3028.59
12751	10850	1.13	45.56	7.66	4.78	0.44	3028.31
12580	8243	0.86	34.61	5.82	3.63	0.33	2300.68
12547	7108	0.74	29.85	5.02	3.13	0.29	1983.89
12557	5274	0.55	22.15	3.73	2.32	0.21	1472.01
12711	14028	1.46	58.91	9.91	6.18	0.57	3915.31
12775	4153	0.43	17.44	2.93	1.83	0.17	1159.13
12398	2175	0.23	9.13	1.54	0.96	0.09	607.06
12399	2175	0.23	9.13	1.54	0.96	0.09	607.06
12694	17169	1.79	72.10	12.13	7.57	0.70	4791.98
12781	4390	0.46	18.43	3.10	1.93	0.18	1225.28
12689	54763	5.71	229.96	38.68	24.14	2.22	15284.72
12579	72525	7.56	304.54	51.23	31.96	2.94	20242.21
12697	5531	0.58	23.23	3.91	2.44	0.22	1543.74
12654	10637	1.11	44.67	7.51	4.69	0.43	2968.86
12655	10552	1.10	44.31	7.45	4.65	0.43	2945.13

Table E-3. Allocation of Pollutant by Segment Number (Continued).

Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
12560	1937	0.20	8.13	1.37	0.85	0.08	540.63
12335	8473	0.88	35.58	5.98	3.73	0.34	2364.87
12343	6270	0.65	26.33	4.43	2.76	0.25	1750.00
12403	16436	1.71	69.02	11.61	7.24	0.67	4587.40
12441	20730	2.16	87.05	14.64	9.14	0.84	5785.88
12443	20737	2.16	87.08	14.65	9.14	0.84	5787.84
12444	20803	2.17	87.36	14.69	9.17	0.84	5806.26
12621	16228	1.69	68.14	11.46	7.15	0.66	4529.34
12634	1753	0.18	7.36	1.24	0.77	0.07	489.27
12653	4652	0.48	19.53	3.29	2.05	0.19	1298.40
12380	2475	0.26	10.39	1.75	1.09	0.10	690.79
12378	7219	0.75	30.31	5.10	3.18	0.29	2014.87
12764	3331	0.35	13.99	2.35	1.47	0.13	929.70
12628	76109	7.93	319.59	53.76	33.54	3.08	21242.53
12618	7260	0.76	30.49	5.13	3.20	0.29	2026.31
12619	13967	1.46	58.65	9.87	6.16	0.57	3898.28
12423	8556	0.89	35.93	6.04	3.77	0.35	2388.04
12709	9590	1.00	40.27	6.77	4.23	0.39	2676.63
12658	5416	0.56	22.74	3.83	2.39	0.22	1511.64
12744	3135	0.33	13.16	2.21	1.38	0.13	875.00
11607	123	0.01	0.52	0.09	0.05	0.00	34.33
12581	18771	1.96	78.82	13.26	8.27	0.76	5239.11
12363	17360	1.81	72.90	12.26	7.65	0.70	4845.29
12367	2373	0.25	9.96	1.68	1.05	0.10	662.32
12642	10611	1.11	44.56	7.49	4.68	0.43	2961.60
12643	1801	0.19	7.56	1.27	0.79	0.07	502.67
12644	12512	1.30	52.54	8.84	5.51	0.51	3492.18
12645	23637	2.46	99.26	16.70	10.42	0.96	6597.24
12594	9856	1.03	41.39	6.96	4.34	0.40	2750.88
12596	9856	1.03	41.39	6.96	4.34	0.40	2750.88
12682	354	0.04	1.49	0.25	0.16	0.01	98.80

Table E-3. Allocation of Pollutant by Segment Number (Continued).

Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
12706	10592	1.10	44.48	7.48	4.67	0.43	2956.30
12707	10591	1.10	44.47	7.48	4.67	0.43	2956.02
12463	8096	0.84	34.00	5.72	3.57	0.33	2259.65
12464	8097	0.84	34.00	5.72	3.57	0.33	2259.93
12466	8099	0.84	34.01	5.72	3.57	0.33	2260.49
12496	918	0.10	3.85	0.65	0.40	0.04	256.22
12597	585	0.06	2.46	0.41	0.26	0.02	163.28
12688	8961	0.93	37.63	6.33	3.95	0.36	2501.08
12690	13667	1.42	57.39	9.65	6.02	0.55	3814.55
12728	1652	0.17	6.94	1.17	0.73	0.07	461.08
12635	5000	0.52	21.00	3.53	2.20	0.20	1395.53
12648	4477	0.47	18.80	3.16	1.97	0.18	1249.56
12726	11976	1.25	50.29	8.46	5.28	0.49	3342.58
12401	9491	0.99	39.85	6.70	4.18	0.38	2649.00
12482	3607	0.38	15.15	2.55	1.59	0.15	1006.74
12647	7816	0.81	32.82	5.52	3.44	0.32	2181.50
12578	7311	0.76	30.70	5.16	3.22	0.30	2040.55
12636	6374	0.66	26.77	4.50	2.81	0.26	1779.03
12659	3876	0.40	16.28	2.74	1.71	0.16	1081.82
12607	7526	0.78	31.60	5.32	3.32	0.30	2100.56
12608	7524	0.78	31.59	5.31	3.32	0.30	2100.00
12767	37637	3.92	158.04	26.58	16.59	1.52	10504.74
12449	23254	2.42	97.65	16.42	10.25	0.94	6490.35
12504	60301	6.29	253.21	42.59	26.58	2.44	16830.41
12135	64	0.01	0.27	0.05	0.03	0.00	17.86
12136	52	0.01	0.22	0.04	0.02	0.00	14.51
12754	121	0.01	0.51	0.09	0.05	0.00	33.77
13345	10622	1.11	44.60	7.50	4.68	0.43	2964.67
12657	12924	1.35	54.27	9.13	5.70	0.52	3607.17
12610	1650	0.17	6.93	1.17	0.73	0.07	460.53
12630	15662	1.63	65.77	11.06	6.90	0.63	4371.37

Table E-3. Allocation of Pollutant by Segment Number (Continued).

Segment	Segment Length (ft)	Pollutant per segment (tons/segment)					
		PM	NO_x	SO_2	CO	VOC	CO_2
12629	15663	1.63	65.77	11.06	6.90	0.63	4371.65
12703	8277	0.86	34.76	5.85	3.65	0.34	2310.17
12616	23610	2.46	99.14	16.68	10.41	0.96	6589.71
12745	13610	1.42	57.15	9.61	6.00	0.55	3798.64
Total	4,259,777	444.02	17,887.46	3,008.77	1,877.46	172.59	1,188,932.25

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APPENDIX F

LOUISIANA OFFSHORE OIL PORT

The Louisiana Offshore Oil Port (LOOP) has multiple emission sources including some that are directly associated with the platform, such as generators and pumps. The LOOP also includes emission sources that are associated with the vessels that use the platform. The vessels would include the tankers that offload their product to the LOOP as well as support vessels that help guide the tankers to and from the mooring points. Details concerning platform and vessel activity were obtained from the LOOP website (LOOP 2001).

Detailed geographic data provided on the LOOP website identifies the approach used by vessels, the waiting area, and the mooring points as well as latitude and longitude coordinates for the platform itself (LOOP 2001).

Platform Sources

The LOOP platform operates one 1000 kW generator and four 7,500 hp pumps. Hours of operation for the generator and pumps were obtained from the GMAQS (U.S. DOI, MMS, 1995); the generator was assumed to run continuously (8,760 hrs/yr) and the pumps operate a total of 13,500 hours/year. It was assumed that 2000 activity was similar to 1995 level. Marine diesel emission factors for these sources were developed based on EPA's marine diesel emission factor equation (EPA 2000):

$$E\ (g/kW\text{-}hr) = A * (\text{Engine Load Factor})^{-x} + B$$

Where:

E is the power base emission factor;

Constant A, intercept B, and exponential x, noted in Tables A-1 and A-2 were obtained from Table 5-1 of the U.S. EPA Office of Air and Radiation's *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For SO_2, it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A* (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

Engine load factors required in this algorithm were obtained from the GMAQS (U.S. DOI, MMS 1995). The values obtained from this algorithm were converted to horsepower and applied to the horsepower data provided to develop the emission factors shown in Tables F-1 and F-2. These emission factors were applied to hours of operation to estimate emissions.

Vessel Emissions

The LOOP also provided detailed information about the individual vessels that used the platform in 2000 (Table F-3) and the line vessels that assisted the oil tankers in getting to and from the mooring points. The same approach used to develop the diesel marine emission factors for the LOOP platform sources was used for the associated vessel emission sources.

The average hours tankers spent approaching the platform in the designated shipping lane were estimated based on the data provided and are summarized in Table F-4.

Where it was reported that two vessels arrived at the LOOP on the same day, it was conservatively assumed that both vessels arrived at the same time. In this study one vessel was assumed to be moored at the LOOP offloading product, while the second vessel waited in the anchorage area. It was also assumed that once the first vessel moved away from the mooring point and maneuvered itself to return to the approach fairway and the mooring master, crew and equipment boarded the second vessel, the second vessel would move out of anchorage and up to the unloading mooring point. Typically it would take 24 hours for the first vessel to unload and 2 hours (or approximately 10% of unloading time) to maneuver away from the mooring which equals 26 hours that the second vessel waited on average at anchorage. Note, this approach provides a conservative estimate of emissions as the second vessel may arrive hours after the first vessel, such that the second vessel's time at anchorage may be less than 26 hours and the actual emissions would be somewhat less than those estimated using these assumptions. Unfortunately, there are no data to quantify how much less actual emissions are from these potential emissions.

It was assumed that the load factor for the approach to the platform was 55% of full engine load. Time spent hoteling and offloading to the platform was estimated based on data provided by the LOOP. It was assumed that during the period of hoteling and offloading the engine load factor was 10% of full engine load.

As with the LOOP platform sources, diesel emission factors were derived from the EPA's marine diesel emission factor equation (see Tables F-5 and F-6) (EPA 2000) and applied to average vessel horsepower and time in mode to estimate emissions (LOOP 2001).

While offloading product to the LOOP, water is pumped into the tanker to provide ballast for the vessels. During this procedure volatile compounds are displaced into the atmosphere. Emissions from ballasting activities were estimated based on the approach used in the GMAQS (U.S. DOI, MMS 1995).

For the support vessels, calculations were developed for the loader and the line vessels. Based on information provided in the LOOP's website (LOOP 2001), it was assumed that each vessel was equipped with two 600 HP engines and operated on average at 25% of full engine load. Diesel emission factors developed for these vessels were derived from EPA's marine diesel emission factor equation (see Table F-7). These emission factors were applied to vessel horsepower rating and hours of operation to estimate emissions. Lifter and responder vessels were not included in the calculations, as hours of operation were not readily available and it was thought that they operated on a less frequent basis than the other support vessels, thus their emissions would be relatively small.

Emission estimates for all sources associated within the LOOP are noted in Table F-8.

Table F-1. 1000kW Generator.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Ave kW rating	Kg/hr	lbs/hr
PM	0.27	1.50	0.2551	0.0059	1,000.00	0.27	0.60
NO_x	10.80	1.50	10.4496	0.1255	1,000.00	10.80	23.82
SO_2*	1.87	N/A	0	1.998	1,000.00	1.87	4.11
CO	1.68	1.00	0	0.8378	1,000.00	1.68	3.69
VOC	0.19	1.50	0	0.0667	1,000.00	0.19	0.42
CO_2	736.80	1.00	648.6	44.1	1,000.00	736.80	1624.35

Assumed operating load = 50%

*For SO_2 fuel sulfur flow (g/kW-hr) = (14.12/(Fractional load) + 205.717)*0.4% or 0.004, using the fuel sulfur concentration of 0.4%.

Table F-2. Four 7,500 hp Pumps.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Ave kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.2551	0.0059	5,592.75	1.46	3.22
NO_x	10.58	1.50	10.4496	0.1255	5,592.75	59.14	130.39
SO_2*	1.75	N/A	0	1.998	5,592.75	9.80	21.61
CO	0.84	1.00	0	0.8378	5,592.75	4.69	10.33
VOC	0.07	1.50	0	0.0667	5,592.75	0.37	0.82
CO_2	692.70	1.00	648.6	44.1	5,592.75	3874.10	8540.84

Assumed operating load = 100%

*For SO_2 fuel sulfur flow (g/kW-hr) = (14.12/(Fractional load) + 205.717)*0.4% or 0.004, using a fuel sulfur concentration of 0.4%.

Table F-3. LOOP Vessel Activity Data.

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Front Breaker	1,049,582	38.05	166,474	1/1/00		25,883.87	19,309.37
Nisyros	950,450	19.9	141,659	1/1/00	1	23,377.56	17,439.66
Kapetan Giorgis	3,259,353	57.48	449,182	1/2/00		54,437.38	40,610.29
Corona Star	1,607,607	38.42	229,073	1/5/00		32,206.37	24,025.95
Alta	945,171	21.7	143,960	1/6/00		23,609.96	17,613.03
Front Warrior	960,420	30.4	150,906	1/7/00		24,311.51	18,136.38
Astro Capella	1,052,221	19.6	157,190	1/8/00		24,946.19	18,609.86
World Phoenix	757,281	10.95	253,988	1/11/00		34,722.79	25,903.20
Front Fighter	828,143	23	150,906	1/12/00		24,311.51	18,136.38
Media Star	1,006,847	20.78	405,010	1/13/00		49,976.01	37,282.10
Maersk Navarin	1,384,944	28	251,280	1/15/00		34,449.28	25,699.16
Star Ohio	948,426	22.7	141,480	1/15/00	1	23,359.48	17,426.17
Argo Elektra	941,494	19.77	281,255	1/16/00		37,476.76	27,957.66
Olympic Sponsor	199,349	6.7	95,022	1/17/00		18,667.22	13,925.75
Alta	939,203	21.9	143,960	1/22/00		23,609.96	17,613.03
Meridian Lion	996,283	18.3	269,445	1/23/00		36,283.95	27,067.82
Astro Canopus	1,050,667	19.68	155,505	1/27/00		24,776.01	18,482.90
Berge Pioneer	523,335	12.2	355,020	1/27/00	1	44,927.02	33,515.56
Phoenix Star	1,012,534	19.63	286,832	1/27/00	1	38,040.03	28,377.86
Atlantic Prosperity	1,137,215	16.3	306,766	1/28/00		40,053.37	29,879.81
New Vision	999,428	16.23	293,327	1/30/00		38,696.03	28,867.24
Safaniy AH	2,125,803	36.3	294,720	1/30/00	1	38,836.72	28,972.19

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Magnolia	543,267	26	280,325	1/31/00		37,382.83	27,887.59
Libra Star	1,553,630	24.1	286,832	2/6/00		38,040.03	28,377.86
Alta	998,891	23.27	143,960	2/7/00		23,609.96	17,613.03
Harriet	815,067	20.18	133,826	2/7/00	1	22,586.43	16,849.47
Empress Des Mers	2,468,182	45.54	417,008	2/8/00		51,187.81	38,186.10
Hawtah	1,114,317	18.8	294,720	2/9/00		38,836.72	28,972.19
Andros Georgios	502,113	14.8	229,043	2/11/00		32,203.34	24,023.69
Astro Canopus	1,048,750	19.1	158,000	2/12/00		25,028.00	18,670.89
Kapetan Michalis	1,229,955	23.1	508,268	2/12/00	1	60,405.07	45,062.18
Front Lady	1,326,618	24.73	279,994	2/14/00		37,349.39	27,862.65
Beryl	248,682	7.1	93,652	2/16/00		18,528.85	13,822.52
Jupiter Glory	1,574,440	26.1	294,096	2/19/00		38,773.70	28,925.18
Polar	985,945	31	151,706	2/21/00		24,392.31	18,196.66
Pacific Ruby	248,569	7.62	94,654	2/22/00		18,630.05	13,898.02
Columba Star	622,119	8.54	299,811	2/23/00		39,350.91	29,355.78
Jahre Viking	1,330,678	19.5	555,843	2/26/00		65,210.14	48,646.77
New Wisdom	2,116,708	35.84	293,326	2/26/00	1	38,695.93	28,867.16
Astro Canopus	1,048,661	18	158,000	2/29/00		25,028.00	18,670.89
Kapetan Hiotis	2,926,900	58.33	406,592	2/29/00	1	50,135.79	37,401.30
Alta	1,013,976	23.8	143,960	3/2/00		23,609.96	17,613.03
Neptune Glory	549,045	7.4	299,127	3/2/00	1	39,281.83	29,304.24
Wilmington	576,919	24.8	86,272	3/5/00		17,783.47	13,266.47
Shaula Star	2,097,631	37.27	296,828	3/6/00		39,049.63	29,131.02
Front Fighter	478,023	7.53	150,906	3/10/00		24,311.51	18,136.38
Luxembourg	1,362,760	20.4	300,000	3/11/00		39,370.00	29,370.02
Narova	826,353	19.5	141,622	3/12/00		23,373.82	17,436.87
Lillo	994,182	27	138,334	3/14/00		23,041.73	17,189.13
Nord Jahre Target	449,084	8.1	139,788	3/14/00	1	23,188.59	17,298.69
Auriga	1,559,074	41.4	404,105	3/15/00		49,884.61	37,213.92
World Prelude	1,325,000	21.58	249,988	3/15/00	1	34,318.79	25,601.82
J. Dennis Bonney	414,104	7.07	152,653	3/18/00		24,487.95	18,268.01
Sks Tweed	521,629	18.6	108,170	3/21/00		19,995.17	14,916.40

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
British Vigilance	1,249,495	38	294,967	3/22/00		38,861.67	28,990.80
Berge Enterprise	2,007,405	36.5	355,003	3/23/00		44,925.30	33,514.28
Soro	1,333,011	20	294,984	3/23/00	1	38,863.38	28,992.08
British Hawk	997,399	22.66	149,066	3/25/00		24,125.67	17,997.75
Mira Star	1,502,794	36.7	416,950	3/26/00		51,181.95	38,181.73
British Harrier	1,025,075	23.1	149,066	3/30/00		24,125.67	17,997.75
Media Star	1,498,540	34.73	405,010	3/30/00	1	49,976.01	37,282.10
Siam	908,690	17.7	295,261	3/30/00	1	38,891.36	29,012.96
Ramlah	2,122,494	34.8	294,720	4/1/00		38,836.72	28,972.19
Atlantic Prosperity	1,599,303	22.7	164,373	4/3/00		25,671.67	19,151.07
Atlantic Liberty	2,115,749	35.1	306,703	4/4/00		40,047.00	29,875.06
Emma Maersk	1,574,419	29.96	294,179	4/6/00		38,782.08	28,931.43
Alta	937,418	23.17	143,960	4/7/00		23,609.96	17,613.03
Berge Pioneer	1,711,155	28.57	355,020	4/8/00		44,927.02	33,515.56
Front Champion	950,662	15.47	303,824	4/8/00	1	39,756.22	29,658.14
Alda Wha	515,328	8.9	280,039	4/10/00		37,353.94	27,866.04
Olymipic Legacy	1,384,367	31.1	298,007	4/10/00	1	39,168.71	29,219.86
Chanda	939,158	20.2	146,155	4/12/00		23,831.66	17,778.41
Equatorial Lion	408,334	12.4	269,219	4/12/00	1	36,261.12	27,050.79
Agios Nikolaos	1,542,218	22.4	277,301	4/13/00		37,077.40	27,659.74
British Harrier	1,023,982	20.77	149,066	4/14/00		24,125.67	17,997.75
Ellen Maersk	924,743	17.4	307,190	4/15/00		40,096.19	29,911.76
Kapetan Giannis	1,001,201	19.9	508,731	4/16/00		60,451.83	45,097.07
New Wisdom	947,015	16.4	293,326	4/17/00		38,695.93	28,867.16
Luxembourg	490,302	7.08	300,000	4/18/00		39,370.00	29,370.02
Almudaina	448,729	9.2	144,927	4/19/00		23,707.63	17,685.89
Libra Star	994,805	19.52	286,832	4/19/00	1	38,040.03	28,377.86
Sabine	845,490	19.79	154,846	4/19/00	1	24,709.45	18,433.25
Princess Susana	1,014,038	27.47	149,890	4/20/00		24,208.89	18,059.83
Orion Star	1,595,124	29.25	300,953	4/21/00		39,466.25	29,441.82
Empress Des Mers	2,447,203	45.4	417,008	4/28/00		51,187.81	38,186.10

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Volans	1,993,274	33.9	356,399	4/28/00	1	45,066.30	33,619.46
Kapetan Panagiotis	1,995,647	33.91	449,842	5/2/00		54,504.04	40,660.02
Alphard Star	1,562,443	24.7	297,094	5/3/00		39,076.49	29,151.06
Andros Georgios	582,426	17.1	229,043	5/3/00	1	32,203.34	24,023.69
British Vigilance	1,461,611	30.4	294,967	5/4/00		38,861.67	28,990.80
Chanda	1,001,302	23.6	146,155	5/4/00	1	23,831.66	17,778.41
Watban	1,955,273	40.42	294,720	5/8/00		38,836.72	28,972.19
Golar Dundee	1,572,916	36.9	297,641	5/11/00		39,131.74	29,192.28
Limburg	1,010,290	23.5	300,000	5/11/00	1	39,370.00	29,370.02
Chios	491,357	10.81	297,051	5/13/00		39,072.15	29,147.82
World Pendant	1,844,414	41.4	249,988	5/13/00	1	34,318.79	25,601.82
Front Breaker	1,049,175	24.8	159,000	5/14/00		25,129.00	18,746.23
Atlantic Liberty	1,892,474	49.73	306,703	5/15/00		40,047.00	29,875.06
New World	539,753	10.3	134,367	5/15/00	1	22,641.07	16,890.24
Kapetan Hiotis	2,467,120	46.71	406,692	5/18/00		50,145.89	37,408.84
Astro Centaurus	1,067,975	19.3	295,552	5/20/00		38,920.75	29,034.88
Sacramento	477,046	8.3	156,000	5/22/00		24,826.00	18,520.20
Argo Elektra	859,673	13.23	281,255	5/25/00		37,476.76	27,957.66
Geres	999,862	25.4	130,770	5/30/00		22,277.77	16,619.22
Luxembourg	1,393,315	19.9	300,000	5/30/00	1	39,370.00	29,370.02
Phoenix Star	1,981,440	36.3	286,832	5/31/00		38,040.03	28,377.86
Eagle Auriga	527,799	17.7	98,421	6/2/00		19,010.52	14,181.85
New Wisdom	907,271	17.4	293,326	6/3/00		38,695.93	28,867.16
Berge Stavanger	2,114,139	44.4	301,590	6/7/00		39,530.59	29,489.82
Boree	900,679	15.4	279,378	6/7/00	1	37,287.18	27,816.23
British Hawk	1,015,528	21.5	149,066	6/8/00		24,125.67	17,997.75
Sovereign Unity	535,242	10.8	302,151	6/10/00		39,587.25	29,532.09
Columba Star	997,103	25.8	299,811	6/13/00		39,350.91	29,355.78
Nordmillennium	1,335,641	25.9	301,342	6/13/00	1	39,505.54	29,471.13
Auriga	842,843	19.9	404,105	6/14/00		49,884.61	37,213.92
Front Rider	598,269	15.1	166,474	6/16/00		25,883.87	19,309.37

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Jahre Viking	1,224,204	46	555,843	6/16/00	1	65,210.14	48,646.77
Chanda	997,223	22.3	146,155	6/17/00		23,831.66	17,778.41
Media Star	2,115,728	37.1	405,010	6/17/00	1	49,976.01	37,282.10
Limburg	1,289,297	23.95	299,364	6/20/00		39,305.76	29,322.10
Nord Jahre Target	387,591	17.3	139,788	6/22/00		23,188.59	17,298.69
Berge Pioneer	1,523,689	29.54	355,020	6/23/00		44,927.02	33,515.56
Golar Glasgow	1,286,960	20.05	297,643	6/24/00		39,131.94	29,192.43
Markab Star	567,580	9.1	296,469	6/24/00	1	39,013.37	29,103.97
Welsh Venture	474,302	14.2	276,601	6/24/00	1	37,006.70	27,607.00
Lillo	949,323	24.8	138,334	6/25/00		23,041.73	17,189.13
Front Maple	948,518	21	132,868	6/28/00		22,489.67	16,777.29
Magdelaine	955,347	16.1	269,451	6/28/00	1	36,284.55	27,068.28
Erati	562,644	16.7	157,196	6/29/00		24,946.80	18,610.31
Paola I	629,742	19.1	104,451	6/29/00	1	19,619.55	14,636.19
Front Climber	529,602	13	166,474	6/30/00		25,883.87	19,309.37
Crown Unity	2,079,200	41.75	295,803	7/1/00		38,946.10	29,053.79
Kraka	2,025,174	48.83	351,952	7/3/00		44,617.15	33,284.40
Ascona	1,491,039	26.27	294,472	7/5/00		38,811.67	28,953.51
Hydra Star	1,064,941	15.4	301,015	7/5/00	1	39,472.52	29,446.50
Chanda	1,021,955	22	146,155	7/6/00		23,831.66	17,778.41
Genmar Zoe	1,004,202	20.1	155,103	7/6/00	1	24,735.40	18,452.61
Pherkad Star	2,072,901	47	296,629	7/7/00		39,029.53	29,116.03
Front Breaker	501,041	14.17	159,000	7/8/00		25,129.00	18,746.23
Else Maersk	1,016,601	16.55	307,190	7/11/00		40,096.19	29,911.76
Nisyros	490,616	11.9	141,659	7/13/00		23,377.56	17,439.66
Alta	1,018,037	23.5	143,960	7/15/00		23,609.96	17,613.03
Front Pride	385,132	6.6	147,322	7/15/00	1	23,949.52	17,866.34
Ghawar	1,603,528	28.6	294,720	7/15/00	1	38,836.72	28,972.19
Polar	980,164	52.45	151,076	7/17/00		24,328.68	18,149.19
British Valour	1,240,462	20.3	294,967	7/18/00		38,861.67	28,990.80
Ramlah	1,068,200	18.7	294,720	7/18/00	1	38,836.72	28,972.19

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Golar Stirling	1,001,764	19.2	297,663	7/19/00		39,133.96	29,193.94
Olympic Breeze	518,111	15.2	268,777	7/20/00		36,216.48	27,017.49
Astro Canopus	530,058	8	155,505	7/24/00		24,776.01	18,482.90
Moscliff	740,003	18.8	252,658	7/26/00		34,588.46	25,802.99
Front Tarim	1,274,798	29.5	295,620	7/27/00		38,927.62	29,040.00
Atlantis	1,027,295	18.99	141,950	7/28/00		23,406.95	17,461.58
Kapetan Giorgis	1,057,985	24.8	449,182	7/29/00		54,437.38	40,610.29
Astro Centaurus	2,087,702	38.65	295,552	7/30/00		38,920.75	29,034.88
Chanda	946,635	20.5	146,155	7/30/00	1	23,831.66	17,778.41
Crown Jewel I	1,829,699	43.9	253,401	8/1/00		34,663.50	25,858.97
Genmar Zoe	1,001,993	21.2	155,103	8/4/00		24,735.40	18,452.61
Front Rider	995,535	22.33	166,474	8/5/00		25,883.87	19,309.37
Overseas Donna	1,079,206	21.93	308,700	8/5/00	1	40,248.70	30,025.53
Kapetan Panagiotis	901,456	16.9	449,842	8/6/00		54,504.04	40,660.02
Alrehab	1,955,291	34	296,246	8/8/00		38,990.85	29,087.17
Safaniyah	2,118,654	36.96	294,720	8/9/00		38,836.72	28,972.19
Raphael	1,623,072	25.97	309,614	8/10/00		40,341.01	30,094.40
Columbia Spirit	548,753	23.2	83,501	8/11/00		17,503.60	13,057.69
Front Driver	525,135	11.5	132,867	8/11/00	1	22,489.57	16,777.22
Alda Wha	1,025,267	40.57	136,623	8/13/00		22,868.92	17,060.22
Jupiter Glory	539,402	10.7	294,097	8/13/00	1	38,773.80	28,925.25
Berge Odel	875,747	26.87	278,801	8/14/00		37,228.90	27,772.76
Arctic Blue	1,819,717	27.2	467,627	8/15/00		56,300.33	42,000.04
Alta	903,209	20.5	143,960	8/19/00		23,609.96	17,613.03
Olympic Legacy	1,038,744	18	298,007	8/19/00	1	39,168.71	29,219.86
North Star	534,345	16.5	146,215	8/20/00		23,837.72	17,782.94
New World	575,539	10.97	134,367	8/21/00		22,641.07	16,890.24
Hellespont Embassy	1,921,781	37.13	400,070	8/22/00		49,477.07	36,909.89
Red Seagull	505,627	15.7	399,843	8/23/00		49,454.14	36,892.79
Margaux	1,509,046	38	269,833	8/26/00		36,323.13	27,097.06

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Atlantic Liberty	1,060,661	20	305,104	8/28/00		39,885.50	29,754.59
Hawtah	1,122,099	20.8	294,720	8/28/00	1	38,836.72	28,972.19
Maersk Estelle	1,413,157	27.7	294,967	8/28/00	1	38,861.67	28,990.80
Chanda	904,679	18.47	146,155	8/30/00		23,831.66	17,778.41
Gemini Star	2,054,840	44.1	297,094	8/30/00	1	39,076.49	29,151.06
James N. Sullivan	500,034	8.4	133,768	8/31/00		22,580.57	16,845.10
Berge Fuji	1,036,878	19.3	296,000	9/2/00		38,966.00	29,068.64
Front Maple	1,005,394	20.4	132,868	9/2/00	1	22,489.67	16,777.29
Nisyros	351,556	9.8	141,659	9/2/00	1	23,377.56	17,439.66
Agios Nikolaos	1,544,747	25.2	277,301	9/3/00		37,077.40	27,659.74
Media Star	2,879,289	52.3	405,010	9/6/00		49,976.01	37,282.10
Mira Star	887,416	24.7	416,950	9/8/00		51,181.95	38,181.73
Andros Georgios	1,131,218	22.1	299,043	9/10/00		39,273.34	29,297.91
Genmar Macedon	1,072,946	27.6	153,090	9/13/00		24,532.09	18,300.94
Eli Maersk	1,010,337	15.9	308,491	9/15/00		40,227.59	30,009.78
Hellespont Capitol	1,535,339	32.4	375,881	9/15/00	1	47,033.98	35,087.35
Polar	963,087	31.6	151,076	9/16/00		24,328.68	18,149.19
Columba Star	2,106,259	43.8	299,811	9/18/00		39,350.91	29,355.78
Jahre Viking	1,108,526	30.6	555,843	9/21/00		65,210.14	48,646.77
Kapetan Hatzis	2,630,417	51.1	406,099	9/21/00	1	50,086.00	37,364.16
Majestic Unity	924,043	16.1	300,549	9/23/00		39,425.45	29,411.38
Marble	535,009	10.1	132,868	9/25/00		22,489.67	16,777.29
Olympia	550,090	15.3	105,488	9/25/00	1	19,724.29	14,714.32
Astro Lyra	919,954	16.4	284,410	9/27/00		37,795.41	28,195.38
Front Guider	1,050,982	21.6	166,474	9/28/00		25,883.87	19,309.37
Corona Star	1,604,596	51.9	229,073	9/29/00		32,206.37	24,025.95
Genmar Macedon	1,080,063	28.9	153,090	9/29/00	1	24,532.09	18,300.94
Maersk Eleo	1,021,982	22.9	294,179	10/1/00		38,782.08	28,931.43
Astro Gamma	784,260	23.6	264,073	10/3/00		35,741.37	26,663.06
Front Chief	982,004	13.5	308,700	10/4/00		40,248.70	30,025.53
Minerva Nounou	1,009,438	18.7	147,450	10/5/00		23,962.45	17,875.99
Sea Splendor	2,880,839	78.2	402,936	10/6/00		49,766.54	37,125.84
Empress Des Mers	1,983,991	36.2	417,008	10/11/00		51,187.81	38,186.10
Genmar Spartiate	1,058,928	26.4	152,700	10/13/00		24,492.70	18,271.55

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Narova	984,572	20.1	141,622	10/13/00	1	23,373.82	17,436.87
J. Bennett Johnston	1,118,992	20.9	305,099	10/15/00		39,885.00	29,754.21
Kapetan Giorgis	600,090	9.9	449,182	10/15/00	1	54,437.38	40,610.29
Wilma Yangtze	525,146	11.1	149,591	10/16/00		24,178.69	18,037.30
Kapetan Giannis	1,090,077	14.5	508,731	10/17/00		60,451.83	45,097.07
Shaula Star	2,060,297	37.4	296,828	10/19/00		39,049.63	29,131.02
Berge Boss	518,144	15.2	310,713	10/20/00		40,452.01	30,177.20
British Progress	996,645	20.4	306,397	10/21/00		40,016.10	29,852.01
Jupiter Glory	1,588,377	30.8	294,097	10/22/00		38,773.80	28,925.25
Sks Tagus	600,199	20.8	108,170	10/23/00		19,995.17	14,916.40
Berge Ichiban	1,079,006	14.3	298,522	10/26/00		39,220.72	29,258.66
Eirini L	566,083	13.6	147,276	10/27/00		23,944.88	17,862.88
Golar Glasgow	1,600,182	24.5	297,643	10/28/00		39,131.94	29,192.43
Moscliff	1,804,613	47.2	252,658	10/29/00		34,588.46	25,802.99
Alta	978,432	21.6	143,960	11/1/00		23,609.96	17,613.03
Seasprite	850,196	19.1	148,500	11/1/00	1	24,068.50	17,955.10
AL Balistar	1,197,193	18.8	286,832	11/2/00		38,040.03	28,377.86
Carina Star	2,105,303	34	300,840	11/3/00		39,454.84	29,433.31
Andros Georgios	571,655	13.9	229,043	11/6/00		32,203.34	24,023.69
Lillo	614,387	20.7	138,334	11/6/00	1	23,041.73	17,189.13
Mirfak Star	2,068,725	39.3	296,779	11/6/00	1	39,044.68	29,127.33
Maersk Estelle	1,459,434	29.4	294,967	11/11/00		38,861.67	28,990.80
Overseas New York	499,265	12.9	90,393	11/11/00	1	18,199.69	13,576.97
Gemini Star	537,197	11.9	297,967	11/12/00		39,164.67	29,216.84
Front Ardenne	1,018,460	24.8	150,733	11/13/00		24,294.03	18,123.35
Golar Edinburgh	1,128,117	26.2	297,656	11/13/00	1	39,133.26	29,193.41
Hellespont Paramount	2,266,125	40.8	369,932	11/16/00		46,433.13	34,639.12
Skyros	481,121	7.8	323,100	11/18/00		41,703.10	31,110.51
Overseas New York	502,775	11.6	90,393	11/19/00		18,199.69	13,576.97
Kapetan Michalis	2,092,402	39.5	508,268	11/20/00		60,405.07	45,062.18
Star Ohio	734,623	18.1	141,480	11/20/00	1	23,359.48	17,426.17
Front Brabant	1,044,042	22.6	154,855	11/22/00		24,710.36	18,433.92
Astro Gamma	1,850,755	49.2	264,073	11/24/00		35,741.37	26,663.06

Table F-3. LOOP Vessel Activity Data (Continued).

Vessel Name	Cargo (BBL)	Hrs	Dead Weight Tonnage	Call Date	Overlap	Ave. HP	Ave. kW
Emilie Maersk	1,036,489	14.7	303,619	11/24/00	1	39,735.52	29,642.70
Overseas New York	503,177	12.2	90,393	11/25/00		18,199.69	13,576.97
Berge Stadt	475,435	8.3	302,103	11/27/00		39,582.40	29,528.47
Alta	939,890	21	143,960	11/29/00		23,609.96	17,613.03
Senang Spirit	666,374	17.2	94,138	11/29/00	1	18,577.94	13,859.14
Ishwari	467,116	10.6	137,294	12/1/00		22,936.69	17,110.77
Media Star	746,885	12	405,010	12/1/00	1	49,976.01	37,282.10
Hydra Star	2,111,721	40.7	310,015	12/3/00		40,381.52	30,124.61
Overseas New York	501,131	12.2	90,393	12/3/00	1	18,199.69	13,576.97
Hamal Star	1,576,319	26.5	296,796	12/6/00		39,046.40	29,128.61
Auriga	2,457,762	50	404,105	12/9/00		49,884.61	37,213.92
Kristhild	1,820,362	45.3	253,999	12/9/00	1	34,723.90	25,904.03
Mira Star	1,000,202	22.8	416,950	12/11/00		51,181.95	38,181.73
Mosocean	840,013	13.3	252,662	12/12/00		34,588.86	25,803.29
Licorne Pacifique	1,385,086	21.4	264,758	12/14/00		35,810.56	26,714.68
Millennium Maersk	1,030,083	15.2	308,492	12/14/00	1	40,227.69	30,009.86
New Horizon	1,005,229	34.9	132,703	12/14/00	1	22,473.00	16,764.86
Alta	1,006,427	21.5	143,960	12/15/00		23,609.96	17,613.03
Pherkad Star	1,081,456	25.6	296,629	12/17/00		39,029.53	29,116.03
Berge Pioneer	2,233,418	36.4	360,717	12/18/00		45,502.42	33,944.80
Astro Capella	829,565	17.2	157,190	12/19/00		24,946.19	18,609.86
Corona Star	1,052,272	23.1	229,073	12/20/00		32,206.37	24,025.95
Chanda	631,786	17.8	141,155	12/21/00		23,326.66	17,401.68
Andros Georgios	603,007	12	229,043	12/22/00		32,203.34	24,023.69
Harriet	977,829	27.8	132,826	12/22/00	1	22,485.43	16,774.13
Front Breaker	1,081,267	25.4	159,000	12/23/00		25,129.00	18,746.23
Jahre Viking	1,580,041	26.5	555,843	12/23/00	1	65,210.14	48,646.77
Front Champion	1,164,645	23.5	306,274	12/24/00		40,003.67	29,842.74
Olympic Legacy	1,057,873	17.8	298,007	12/25/00		39,168.71	29,219.86
Christina	461,211	10.9	308,000	12/28/00		40,178.00	29,972.79
Sea Splendor	2,084,445	35.8	402,936	12/30/00		49,766.54	37,125.84
Sums:	316,338,690	6612	255,268	275	71	9,584,315.47	7,149,899.34

Source: LOOP 2001.

Table F-4. Summary of Vessel Activity.

Idling (10% of full engine load)			
Number of calls:	275		
Average hours per unload:	24		
Total hours at unloading:	6,612		
Percentage vessels to anchorage:	26		
Total time at anchorage:	1,878		
Total hours at idle	8,489		
Approach (55% of full engine load)			
Number of calls:	275		
Distance of safety fairway (km):	65		
Vessel speed (km/hr):	10.186		
Time to approach:	6.38		
Total time at approach	1,754.86		
Ballasting			
Number of calls:	275		
VOC emissions per call (tons):	2.13		
Total annual VOC from ballasting (tons)	585.75		
		Ave. HP	Ave. kW
Average Dead Weight Tonnage of tanker:	255,268	34,852.06	25,989.18

Source: LOOP 2001.

Table F-5. Emission Factors for Approaching Tankers.

Activity Data

		Ave. HP	Ave. kW
Average DWT* of tanker	255,268	34,852	25,989

* DWT = Dead weight tonnage.

Approach

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.2696	1.5	0.2551	0.0059	25,989	7,005.8	15.44
NO_x	10.7573	1.5	10.4496	0.1255	25,989	279,572.7	616.35
SO_2*	1.8493	N/A	0	1.998	25,989	48,060.9	105.95
CO	1.5233	1	0	0.8378	25,989	39,588.6	87.27
VOC	0.1635	1.5	0	0.0667	25,989	4,249.9	9.36
CO_2	728.7818	1	648.6	44.1	25,989	18,940.4	41,756.10

Assumed operating load = 55%

*For SO_2 fuel sulfur flow (g/kW-hr) = (14.12/(Fractional load) + 205.717)*0.4% or 0.004, using a fuel sulfur concentration of 0.4%.

Table F-6. Emission Factors for Idle Tankers.

Activity Data

		Ave. HP	Ave. kW
Average DWT of tanker	255,268	34,852	25,989

Idle

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.4417	1.5	0.2551	0.0059	25,989	11.48	25.31
NO_x	14.41826	1.5	10.4496	0.1255	25,989	374.72	826.10
SO_2*	2.768189	N/A	0	1.998	25,989	71.94	158.61
CO	8.378	1	0	0.8378	25,989	217.74	480.02
VOC	2.109239	1.5	0	0.0667	25,989	54.81	120.85
CO_2	1089.6	1	648.6	44.1	25,989	28,317.81	62,429.44

Assumed operating load = 10%

*Fuel sulfur flow (g/kW-hr) = (14.12/(Fractional load) + 205.717)*0.4% or 0.004, using a fuel sulfur concentration of 0.4%.

Table F-7. Emission Factors for Support Vessels.

Support Vessels (2) with total brake horsepower of 1200

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.3023	1.5	0.2551	0.0059	894.84	0.27	0.60
NO_x	11.4536	1.5	10.4496	0.1255	894.84	10.25	22.60
SO_2*	2.091107	N/A	0	1.998	894.84	1.87	4.1
CO	3.3512	1	0	0.8378	894.84	3.00	6.61
VOC	0.5336	1.5	0	0.0667	894.84	0.48	1.05
CO_2	825	1	648.6	44.1	894.84	738.24	1,627.53

Assumed Operating Load = 25%

* For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717* fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table F-8. LOOP Emissions.

Pollutant	Platform		Tankers		Support Vessels*	Total (tons/year)
	Generator (tons/year)	Pumps (tons/year)	Idle (tons/year)	Approach (tons/year)	Line Vessels (tons/year)	
PM	2.62	21.72	107.41	13.55	1.97	147.28
NO_x	104.33	880.12	3,506.49	540.80	74.69	5,106.44
SO_2	18.05	146.22	674.28	92.97	13.67	945.19
CO	16.18	69.73	2,037.51	76.58	21.85	2,221.85
VOC	1.82	5.55	512.96	8.22	3.48	532.04
CO_2	7,114.65	57,650.64	264,988.55	36,638.04	5,380.24	371,772.13

Ballasting	
Number of calls:	275.00
VOC emissions per call (tons):	2.13
Total annual VOC from ballasting (tons)	585.75

* Assumes 6,566 hours of operation for support vessels.
  1,755 hours of operation for tanker approach to/from LOOP.
  8,489 hours of operation for tanker idling at LOOP.
  8,760 hours of operation for platform generators.
  13,500 hours of operation for platform pumps.

References

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APPENDIX G

VESSEL LIGHTERING

The Coast Guard provided activity data for vessel lightering in the GOM (Thomas 2001, McClellan 2002). As lightering occurs, the ships are also ballasting, so ballasting emissions were included with the lightering emissions. To calculate the emissions from the ships involved in the lightering process, activity data was obtained, which included the amount of petroleum product lightered, the time period tankers spend in lightering zone, and the number of ships involved in the process. Vessel lightering occurs with two types of vessels; large oil tankers which offload the oil product, typically having an average dead weight tonnage (DWT) of 250,000, and smaller escort vessels that have an average DWT of 75,000. These smaller vessels carry on average 500,000 barrels of product from the oil tankers to port. The total number of escort vessel trips was estimated by dividing the total number of barrels of product handeled in the lightering zones by the average storage capacity of the escort vessels (see Table G-1).

Specific activity data for individual lightering zones were not available, but Coast Guard staff did provide approximate estimates for each zone (see Table G-2).

The location of each of the lightering zones was identified and the distance to port was calculated. It was assumed that escort vessels would travel at 12 miles per hour. Based on this assumed speed and the calculated distance from port of each lightering zones, hours were calculated for the vessel to make the round trip from port to lightering zone and back to port. Time spent (1 hour) traveling in Texas state waters (extending 12 miles from shore seaward) was excluded from our activity estimates.

The collected activity data were applied to diesel emission factors based on the EPA marine diesel emission factor equation (EPA 2000):

$$E\ (\text{g/kW-hr}) = A * (\text{Load Factors})^{-x} + B$$

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables G-3, G-4, and G-5 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For SO_2, it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A * (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

The emission factor equation used assumptions about engine horsepower and load factors provided in the GMAQS. These power-based emission factors were applied to average horsepower ratings for the large cargo vessels and the smaller escort vessels to estimate emissions.

Evaporative emissions associated with the lightering and ballasting operations were calculated by applying total organic carbon (TOC) emission factors obtained from EIIP documents (EIIP 2001) to the amount of oil lightered:

Evaporative Lightering Emission Equation

Emissions = Crude oil * EF
= 344,252,000 barrels * 42 gallons/barrel * 0.86 lbs of TOC/10^3 gal of crude oil * ton/2000 * (0.85 VOC/TOC)
= 5,284.61 tons of VOC

Evaporative Ballasting Emission Equation

Emissions = Capacity * 40% of capacity ballasted * EF
= 344,252,000 barrels *0.4* 42 gallons/barrel * 0.86 lbs of VOC /10^3 gal of crude oil * ton/2000 * (0.85 VOC/TOC)
= 2,113.84 tons of VOC

All vessel lightering emissions are summarized in Table G-6.

Table G-1. Summary of Lighting Activity Data.

Large Oil Vessels		
Time	2-6 days, average = 4 days (96 hours)	Thomas 2001
Ships	246 ships in 2000	McClellan 2002
DWT	200,000 to 300,000, average 250,000	McClellan 2002
Escort Vessels		
Time	2-6 days, average = 4 days (96 hours)	Thomas 2001
Trips*	344,252,000/500,000 = 688.5	McClellan 2002; Thomas 2001
DWT	50,000 to 100,000, average 75,000	McClellan 2002

*Total barrels in 2000 was 344,252,000. Escort vessels carry 500,000 barrels.

Table G-2. Location of Lightering Zones and Average Travel Distance.

Zone	Latitude	Longitude	Use	Distance
South Sabine Lightering Zone	28.30 N	93.40 W	20%	290.86 miles
Galveston Lightering Zone 1	28.35 N	94.30 W	40%	282.55 miles
Galveston Lightering Zone 2	28.40 N	94.10 W	40%	287.64miles
	Average Distance:			286.25 miles
	Average Roundtrip Distance:			572.49 miles
	Roundtrip minus state:			548.5 miles
	Roundtrip time minus state:			45.7 hrs
	Total hours for all ships:			31,469 hrs

Table G-3. Large Oil Vessel Emission Factors.

Activity Data			
DWT	Ave. HP	Ave. kW	Operating Load
250,000.00	34,320.00	25,592.42	10%

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Ave kW rating	Kg/hr	lbs/hr
PM	0.44	1.50	0.26	0.01	25,592	11.30	24.92
NO_x	14.42	1.50	10.45	0.13	25,592	369.00	813.49
SO_2*	2.77	N/A	0.00	2.00	25,592	70.84	156.18
CO	8.38	1.00	0.00	0.84	25,592	214.41	472.70
VOC	2.11	1.50	0.00	0.07	25,592	53.98	119.01
CO_2	1,089.60	1.00	648.60	44.10	25,592	27,885.51	61,476.38

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table G-4. Escort Vessels (Traveling to Lightering Zone and Back to Port) Emission Factors.

Activity Data			
DWT	Ave. HP	Ave. kW	Operating Load
75,000.00	16,645.00	12,412.18	80%

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Ave kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	12,412.18	3.27	7.21
NO_x	10.62	1.50	10.45	0.13	12,412.18	131.88	290.74
SO_2*	1.78	N/A	0.00	2.00	12,412.18	22.10	48.73
CO	1.05	1.00	0.00	0.84	12,412.18	13.00	28.66
VOC	0.09	1.50	0.00	0.07	12,412.18	1.16	2.55
CO_2	703.73	1.00	648.60	44.10	12,412.18	8,734.76	19,256.65

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table G-5. Escort Vessels (Idle) Emission Factors.

Activity Data			
DWT	Ave. HP	Ave. kW	Operating Load
75,000	16,645	12,412	10%

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Ave kW rating	Kg/hr	lbs/hr
PM	0.44	1.50	0.26	0.01	12,412.18	5.48	12.09
NO_x	14.42	1.50	10.45	0.13	12,412.18	178.96	394.54
SO_2*	2.77	N/A	0.00	2.00	12,412.18	34.36	75.75
CO	8.38	1.00	0.00	0.84	12,412.18	103.99	229.25
VOC	2.11	1.50	0.00	0.07	12,412.18	26.18	57.72
CO_2	1,089.60	1.00	648.60	44.10	12,412.18	13,524.31	29,815.69

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table G-6. Emission Estimates for Lightering Operations (tons/year).

Pollutant	Lightering	Ballasting	Large Oil Vessels	Escort Vessels	
				Travel	Idle
PM	--	--	294.25	113.40	142.71
NO_x	--	--	9,605.73	4,574.72	4,658.72
SO_2	--	--	1,844.22	766.75	894.44
CO	--	--	5,581.59	450.96	2,707.04
VOC	5284.61	2113.84	1,405.22	40.12	681.52
CO_2	--	--	725,913.15	302,998.43	352,063.65

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APPENDIX H

COMMERCIAL FISHING

Commercial fishing data for 2000 were provided by the National Oceanic & Atmospheric Administration's National Marine Fisheries Service (NMFS). Separate activity data were provided for the three different types of offshore fishing activities that occur in the GOM, pelagic long line, reef, and shrimp fishing (Cramer 2001, Patella 2001, Poffenberger 2001). It should be noted that fishing operations have significant seasonal variation, the annual emission estimates developed in this report need to be carefully evaluated to get seasonal emission estimates.

The long line activity data set was very large and is not included in this report, but will be included in the electronic activity data set. Note, even though the long line data set provides a lot of vessel-specific data, collectively long line emissions are relatively small. The activity data for reef and shrimp fishing operations are included in Tables H-1 and H-2, respectively.

The activity data for these different fishing operations were provided in spatial terms of latitude and longitude of pelagic long line fishing operations and in NMFS' geographic grid for reef and shrimp fishing.

For each of the three different fishing activities, diesel emission factors were derived based on the EPA marine diesel emission factor equation (EPA 2000):

$$E\ (g/kW\text{-}hr) = A * (\text{Load Factors})^{-x} + B$$

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables H-3, H-4, and H-5 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For SO_2, it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A * (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

These power-based emission factors are applied to average horsepower ratings for commercial fishing vessels and hours of operation to estimate emissions (see Table H-6). This emission estimating approach used assumptions about horsepower and load factors provided in the GMAQS (U.S. DOI, MMS 1995).

Table H-1. Reef Fishing Activity and Emissions Data (tons/year).

NMFS Area	Vessels	Trips	Duration (days)	Duration (hours)	PM	NO_x	SO_2	CO	VOC	CO_2
10	86	724	2,334	56,016	3.63	146.46	24.55	14.44	1.28	9,700.48
11	70	615	1,623	38,952	2.52	101.84	17.07	10.04	0.89	6,745.45
12	14	82	225	5,400	0.35	14.12	2.37	1.39	0.12	935.14
13	73	984	1,744	41,856	2.71	109.44	18.34	10.79	0.96	7,248.34
14	78	474	1,381	33,144	2.15	86.66	14.52	8.54	0.76	5,739.66
15	54	371	1,031	24,744	1.60	64.70	10.84	6.38	0.57	4,285.00
16	55	411	1,194	28,656	1.86	74.92	12.56	7.38	0.66	4,962.46
17	55	712	2,118	50,832	3.29	132.91	22.28	13.10	1.17	8,802.75
18	43	391	1,142	27,408	1.78	71.66	12.01	7.06	0.63	4,746.34
19	35	238	678	16,272	1.05	42.54	7.13	4.19	0.37	2,817.88
20	25	170	569	13,656	0.88	35.71	5.98	3.52	0.31	2,364.86
21	18	115	248	5,952	0.39	15.56	2.61	1.53	0.14	1,030.73
Total	606	5,287	14,287	342,888	22.22	896.52	150.26	88.37	7.87	59,379.06

Table H-2. Shrimp Fishing Activity and Emissions Data (tons/year).

NMFS Area	Activity (hrs)	PM	NO_x	SO_2	CO	VOC	CO_2
1	1,051	0.07	2.75	0.46	0.27	0.02	182.07
2	7,856	0.51	20.54	3.44	2.02	0.18	1,360.53
3	1,874	0.12	4.90	0.82	0.48	0.04	324.52
4	918	0.06	2.40	0.40	0.24	0.02	159.03
5	441	0.03	1.15	0.19	0.11	0.01	76.29
6	1,782	0.12	4.66	0.78	0.46	0.04	308.55
7	2,599	0.17	6.80	1.14	0.67	0.06	450.08
8	1,763	0.11	4.61	0.77	0.45	0.04	305.27
9	721	0.05	1.88	0.32	0.19	0.02	124.79
10	6,406	0.42	16.75	2.81	1.65	0.15	1,109.39
11	20,853	1.35	54.52	9.14	5.37	0.48	3,611.22
12	10,201	0.66	26.67	4.47	2.63	0.23	1,766.59
13	36,869	2.39	96.40	16.16	9.50	0.85	6,384.74
14	35,858	2.32	93.76	15.71	9.24	0.82	6,209.70
15	14,153	0.92	37.00	6.20	3.65	0.32	2,450.91
16	16,345	1.06	42.74	7.16	4.21	0.37	2,830.55
17	30,655	1.99	80.15	13.43	7.90	0.70	5,308.70
18	30,000	1.94	78.44	13.15	7.73	0.69	5,195.19
19	33,900	2.20	88.64	14.86	8.74	0.78	5,870.61
20	10,779	0.70	28.18	4.72	2.78	0.25	1,866.57
21	9,008	0.58	23.55	3.95	2.32	0.21	1,560.00
Total	274,034	17.76	716.49	120.09	70.62	6.29	47,455.30

Table H-3. Reef Fishing Emission Factors.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Average KW rating	kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	223.71	0.06	0.13
NO_x	10.62	1.50	10.45	0.13	223.71	2.38	5.23
SO_2*	1.78	N/A	0.00	2.00	223.71	0.04	0.88
CO	1.05	1.00	0.00	0.84	223.71	0.23	0.52
VOC	0.09	1.50	0.00	0.07	223.71	0.02	0.05
CO_2	703.73	1.00	648.60	44.10	223.71	157.43	346.35

Assuming operating load is 80% (EPA 2000).
From GMAQS, diesels range from 100 to 500 hp average assumed to be 300 hp = 223.71Kw
For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

H-4. Shrimp Fishing Emission Factors.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Average KW rating	kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	223.71	0.06	0.13
NO_x	10.62	1.50	10.45	0.13	223.71	2.38	5.23
SO_2*	1.78	N/A	0.00	2.00	223.71	0.40	0.88
CO	1.05	1.00	0.00	0.84	223.71	0.23	0.52
VOC	0.09	1.50	0.00	0.07	223.71	0.21	0.05
CO_2	703.73	1.00	648.60	44.10	223.71	157.43	346.35

Assuming operating load is 80% (EPA 2000).
From GMAQS, diesels range from 100 to 500 hp average assumed to be 300 hp = 223.71 Kw
For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table H-5. Long Line Emission Factors.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Average kW rating	kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	223.71	0.06	0.13
NO_x	10.62	1.50	10.45	0.13	223.71	2.38	5.23
SO_2*	1.78	N/A	0.00	2.00	223.71	0.40	0.88
CO	1.05	1.00	0.00	0.84	223.71	0.23	0.52
VOC	0.09	1.50	0.00	0.07	223.71	0.02	0.05
CO_2	703.73	1.00	648.60	44.10	223.71	157.43	346.35

Assuming operating load is 80% (EPA 2000).
From GMAQS, diesel range from 100 to 500 hp average assumed to be 300 hp = 223.71 Kw.
For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table H-6. Emission Estimates for Commercial Fishing Operations.

Pollutant	Longline Emissions (tons)	Reef Emissions (tons)	Shrimp Emissions (tons)	Total Emissions (tons)
PM	7.08	22.22	17.76	47.06
NO_x	285.58	896.52	716.49	1,898.59
SO_2	47.86	150.26	120.09	318.21
CO	28.15	88.37	70.62	187.13
VOC	2.51	7.87	6.29	16.66
CO_2	18,914.69	59,379.06	47,455.30	125,749.05

Note: total hours of operation for: long line fishing is 109,208 hours/year, reef fishing is 342,888 hours/year, shrimp is 274,034 hours year.

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APPENDIX I

MILITARY VESSEL OPERATIONS

Coast Guard Vessels

The Coast Guard provided activity data for their vessels operating in the Gulf of Mexico (Peschke 2002). The data included size of boat (i,e., either 87 foot, 110 foot, or 175 foot), the number of engines for each boat type, the horsepower of each engine, the total number of operating hours, and the percentage of time each vessel spent in the OCS. These data are shown in Table I-1. From these data, the total number of hours operating in the OCS were calculated for each type of boat. Using the total operating hours and assuming a load factor of 80%, emission estimates for each boat type were calculated using emission factors derived from the EPA's marine diesel emission factor equation. This emission factor equation is based on the following algorithm (EPA 2000)

E (g/kW-hr) = A * (Load Factors) $^{-x}$ +B

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables I-2, I-3, and I-4 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For $SO_{2,}$ it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A * (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

These power based emission factors were applied the vessel horsepower ratings and hours of operation to estimate emissions. Total emissions for all Coast Guard vessels operating in the Gulf of Mexico's OCS were then determined. These estimates are given in Table I-5.

Naval Vessels

Repeated and unsuccessful attempts to obtain activity data from the Navy necessitated that gross assumptions be made for the purpose of this inventory. These assumptions include that naval vessel fleet remained constant over the period from 1995 to 2000, that vessel type, engine type, and horsepower also remained the same. These 1995 activity data were provided in the GMAQS report in Table N-19 (U.S. DOI, MMS 1995).

In 1995, the Navy reported activity data for vessels of three engine types, diesel engines, steam engines, and turbine engines. Diesel engines emission factors were updated using the EPA's marine diesel emission factor equation (EPA 2000).

$$E\ (g/kW\text{-}hr) = A * (Load\ Factors)^{-x} + B$$

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables I-6 to I-12 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For $SO_{2,}$ it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A * (Fuels Sulfur Flow in g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

A load factor of 80% was used, based on the assumption that naval vessels would operate at a similar power load to Coast Guard vessels. Hours of operation were assumed, for the purposes of this inventory, to be 24 hours per day, 365 days per year as more accurate activity data were not provided by the Navy. It is acknowledged that this is probably an overestimation of activity and actual activity would be somewhat less. The derived emission factors were applied to vessel horsepower and hours of operation to estimate emissions. The estimated emissions from these marine diesel engines are provided in Table I-13.

Steamship and turbine vessel emission estimates were determined differently as the associated emission factors have not been updated, therefore, the older fuel-based factors were used. The emission estimation equation used for this source category is given as follows:

Emission Rate = Emission Factor * Fuel Consumption

Diesel turbine and steamship fuel consumption data supplied by the Navy in the GMAQS report is noted in Table I-14 and I-15, respectively. It should be noted that residual fuel consumption reported in the GMAQS seems relatively low, and it is anticipated that actual fuel consumption rates would be higher. Updated emission factors from the EPA's AP-42, Volume 1, Chapter 3 (EPA 2002) were used for turbines, and data from the EPA's *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and other Nonroad Components of the National Emission Inventory* (EPA 2003) were used for steam engines (see Table I-17). A conversion from pounds per year to tons per year was performed. Emissions calculated for each pollutant type for turbines and steam engines are shown in Table I-18 and Table I-19, respectively. Note, the vessel types shown in Tables I-6 to I-13 are abbreviations used in the GMAQS (U.S. DOI, MMS 1995).

Once emission estimates were calculated for each engine type, total emissions for all naval vessels are summarized in Table I-20. Total estimates for each pollutant for all military vessels in the Gulf of Mexico are summarized in Table I-21. It should be noted that as the Navy data have not been updated with more recent activity data, there is considerable uncertainty associated with the estimates.

Table I-1. Coast Guard Vessels.

Vessel Size	No of Boats	No of Engines	Total No of Engines	Horse-power per Engine	Operating Hours per Boat	Total Operating Hrs for all Engines	Percent of Time Spent in OCS	Total Operating Hrs in OCS per yr
87 Ft	14	2	28	1,475	1,800	50,400	80%	40,320
110 Ft	1	2	2	6,800	1,800	3,600	80%	2,880
175 Ft	2	2	4	1,700	1,200	4,800	80%	3,840

Table I-2. 87-Foot Coast Guard Vessels.

Activity Data			
Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
80%	1,475	1,099.91	40,320

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	1,099.91	0.29	0.64
NO_x	10.62	1.50	10.45	0.13	1,099.91	11.69	25.76
SO_2*	1.78	N/A	0.00	2.00	1,099.91	1.96	4.32
CO	1.05	1.00	0.00	0.84	1,099.91	1.15	2.54
VOC	0.09	1.50	0.00	0.07	1,099.91	0.10	0.23
CO_2	703.73	1.00	648.60	44.10	1,099.91	774.03	1,706.43

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-3. 110-Foot Coast Guard Vessels.

Activity Data			
Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
80%	6,800.00	5,070.76	2,880.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	5,070.76	1.34	2.94
NO_x	10.62	1.50	10.45	0.13	5,070.76	53.88	118.78
SO_2*	1.78	N/A	0.00	2.00	5,070.76	9.03	19.91
CO	1.05	1.00	0.00	0.84	5,070.76	5.31	11.71
VOC	0.09	1.50	0.00	0.07	5,070.76	0.47	1.04
CO_2	703.73	1.00	648.60	44.10	5,070.76	3,568.42	7,866.94

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-4. 175-Foot Coast Guard Vessels.

Activity Data			
Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
80%	1,700.00	1,267.69	3,840.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	1,267.69	0.33	0.74
NO_x	10.62	1.50	10.45	0.13	1,267.69	13.47	29.69
SO_2*	1.78	N/A	0.00	2.00	1,267.69	2.26	4.98
CO	1.05	1.00	0.00	0.84	1,267.69	1.33	2.93
VOC	0.09	1.50	0.00	0.07	1,267.69	0.12	0.26
CO_2	703.73	1.00	648.60	44.10	1,267.69	892.11	1,966.74

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-5. Emission Estimates for Coast Guard Vessels (tons/year).

Pollutant	87 Ft Vessel	110 Ft Vessel	175 Ft Vessel	Total for All Vessels
PM	12.87	4.24	1.41	18.53
NO_x	519.40	171.04	57.01	747.46
SO_2*	87.05	28.67	9.56	125.28
CO	51.19	16.86	5.62	73.67
VOC	4.56	1.50	0.50	6.56
CO_2	34,401.67	11,328.39	3,776.13	49,506.19

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-6. Naval Vessel: MSO.

Activity Data				
Engines	Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
4	80%	575.00	428.78	35,040.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kW rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	428.78	0.11	0.25
NO_x	10.62	1.50	10.45	0.13	428.78	4.56	10.04
SO_2*	1.78	N/A	0.00	2.00	428.78	0.76	1.68
CO	1.05	1.00	0.00	0.84	428.78	0.45	0.99
VOC	0.09	1.50	0.00	0.07	428.78	0.04	0.09
CO_2	703.73	1.00	648.60	44.10	428.78	301.74	665.22

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-7. Naval Vessel: MCM.

Activity Data							
Engines	Operating Load	Ave. HP	Ave. kW	Total Engine Hrs			
4	80%	600	447.42	35,040			
Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.5	0.2551	0.0059	447.4	0.12	0.26
NO_x	10.62	1.5	10.4496	0.1255	447.4	4.75	10.48
SO_2*	1.78	N/A	0	1.998	447.4	0.80	1.76
CO	1.05	1	0	0.8378	447.4	0.47	1.03
VOC	0.09	1.5	0	0.0667	447.4	0.04	0.09
CO_2	703.73	1	648.6	44.1	447.4	314.86	694.1

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-8. Naval Vessel: PHM.

Activity Data							
Engines	Ave Load Factor	Ave. HP	Ave. kW	Total Engine Hrs			
2	80%	800	596.56	17,520			
Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.5	0.2551	0.0059	596.6	0.16	0.35
NO_x	10.62	1.5	10.4496	0.1255	596.6	6.34	13.97
SO_2*	1.78	N/A	0	1.998	596.6	1.06	2.34
CO	1.05	1	0	0.8378	596.6	0.62	1.38
VOC	0.09	1.5	0	0.0667	596.6	0.06	0.12
CO_2	703.73	1	648.6	44.1	596.6	419.81	925.5

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-9. Naval Vessel: TAG.

Activity Data				
Engines	Ave Load Factor	Ave. HP	Ave. kW	Total Engine Hrs
2	80%	1,400.00	1,043.98	17,520.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	1,043.98	0.27	0.61
NO_x	10.62	1.50	10.45	0.13	1,043.98	11.09	24.45
SO_2*	1.78	N/A	0.00	2.00	1,043.98	1.86	4.10
CO	1.05	1.00	0.00	0.84	1,043.98	1.09	2.41
VOC	0.09	1.50	0.00	0.07	1,043.98	0.10	0.21
CO_2	703.73	1.00	648.60	44.10	1,043.98	734.67	1,619.66

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-10. Naval Vessel: TAGS(50).

Activity Data				
Engines	Operating Factor	Ave. HP	Ave. kW	Total Engine Hrs
1	80%	2,500.00	1,864.25	8,760.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	1,864.25	0.49	1.08
NO_x	10.62	1.50	10.45	0.13	1,864.25	19.81	43.67
SO_2*	1.78	N/A	0.00	2.00	1,864.25	3.32	7.32
CO	1.05	1.00	0.00	0.84	1,864.25	1.95	4.30
VOC	0.09	1.50	0.00	0.07	1,864.25	0.17	0.38
CO_2	703.73	1.00	648.60	44.10	1,864.25	1,311.92	2,892.26

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-11. Naval Vessel: LSD.

Activity Data				
Engines	Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
4.00	80%	10,250.00	7,643.43	35,040.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	7,643.43	2.01	4.44
NO_x	10.62	1.50	10.45	0.13	7,643.43	81.21	179.04
SO_2*	1.78	N/A	0.00	2.00	7,643.43	13.61	30.01
CO	1.05	1.00	0.00	0.84	7,643.43	8.00	17.65
VOC	0.09	1.50	0.00	0.07	7,643.43	0.71	1.57
CO_2	703.73	1.00	648.60	44.10	7,643.43	5,378.87	11,858.26

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-12. Naval Vessel: TAGS(40).

Activity Data				
Engines	Operating Load	Ave. HP	Ave. kW	Total Engine Hrs
2	80%	12,000.00	8,948.40	17,520.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	8,948.40	2.36	5.20
NO_x	10.62	1.50	10.45	0.13	8,948.40	95.08	209.61
SO_2*	1.78	N/A	0.00	2.00	8,948.40	15.94	35.13
CO	1.05	1.00	0.00	0.84	8,948.40	9.37	20.66
VOC	0.09	1.50	0.00	0.07	8,948.40	0.83	1.84
CO_2	703.73	1.00	648.60	44.10	8,948.40	6,297.21	13,882.84

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-13. Naval Vessel: TAK(II).

Activity Data				
Engines	Ave Load Factor	Ave. HP	Ave. kW	Total Engine Hrs
2	80%	13,500.00	10,066.95	17,520.00

Emission Factors							
Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	Avg kw rating	Kg/hr	lbs/hr
PM	0.26	1.50	0.26	0.01	10,066.95	2.65	5.84
NO_x	10.62	1.50	10.45	0.13	10,066.95	106.96	235.81
SO_2*	1.78	N/A	0.00	2.00	10,066.95	17.93	39.52
CO	1.05	1.00	0.00	0.84	10,066.95	10.54	23.24
VOC	0.09	1.50	0.00	0.07	10,066.95	0.94	2.07
CO_2	703.73	1.00	648.60	44.10	10,066.95	7,084.36	15,618.19

For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table I-14. Summary of Emission Estimates for Naval Diesel Vessels (tons/year).

Pollutant	Vessel								Total
	MSO	MCM	PHM	TAG	TAGS(50)	LSD	TAGS(40)	TAK(II)	
PM	4.36	4.55	3.03	5.31	4.74	77.75	45.51	51.20	196.45
NO_x	175.96	183.61	122.41	214.22	191.27	3,136.75	1,836.15	2,065.67	7,926.04
CO	17.34	18.10	12.07	21.11	18.85	309.17	180.98	203.60	781.23
VOC	1.54	1.61	1.07	1.88	1.68	27.52	16.11	18.12	69.54
CO_2	11,654.64	12,161.36	8,107.58	14,188.26	12,668.09	207,756.63	121,613.64	136,815.34	524,965.53
SO_2	29.49	30.77	20.52	35.90	32.06	525.73	307.74	346.21	1,328.43

Table I-15. Diesel Turbine Fuel Consumption.

Vessel	Fuel Used (1000L/yr)
CG	333.84
DD	129.08
FFG	131.31

Table I-16. Naval Steamship Fuel Consumption.

Vessel	Fuel Consumption (1000L)
LPH	93.79
FF	393.45
AVT	8431.37

Table I-17. Naval Diesel Turbine Emission Factor Conversions.*

Pollutant	lb/MMBtu	lb/1000gal	lb/1000L
NO_x	0.88	122.32	32.19
CO	0.00	0.46	0.12
CO_2	157.00	21,823.00	5,742.89
SO_2	0.40	56.16	14.78
VOC	0.00	0.06	0.01
PM	0.01	1.67	0.44

*Note: obtained from AP-42 (EPA 2002).

Table I-18. Steamship Emission Factors.

Pollutant	Emission Factor lbs/1000L
NO_x	14.38
CO	0.977
SO_2	85.9
VOC	0.33
PM	6.816

Source: EPA 2002.

Table I-19. Emission Estimates for Naval Turbine Engines (tons/year).

Pollutant	Vessels			Total
	CG	DD	FFG	
NO_x	5.37	2.08	2.11	9.56
CO	0.02	0.01	0.01	0.04
CO_2	958.60	370.65	377.05	1,706.30
VOC	0.00	0.00	0.00	0.00
PM	0.07	0.03	0.03	0.13
SO_2	2.47	0.95	0.97	4.39

Table I-20. Emission Estimates for Naval Steam Engines (tons/year).

Pollutant*	Vessels			Total
	LPH	FF	AVT	
NO_x	0.67	2.83	60.62	64.12
CO	0.05	0.19	4.12	4.36
SO_2	4.03	16.90	362.13	383.05
VOC	0.02	0.06	1.39	1.47
PM	0.32	1.34	28.73	30.39

* Emission factors are not available for CO_2.

Table I-21. Total Emission Estimates from All Naval Vessels (tons/year).

Pollutant	Diesel	Steamships*	Turbine	Total
PM	196.45	30.39	0.13	226.98
NO_x	7,926.04	64.12	9.56	7,999.73
CO	781.23	4.36	0.04	785.62
VOC	69.54	1.47	0.00	71.01
CO_2	524,965.53		1,706.30	526,671.83
SO_2	1,328.43	383.05	4.39	1,715.87

* Emission estimates are not available for CO_2.

Table I-22. Summary of Emission Estimates from All Military Vessels (tons/year).

Pollutant	Naval Vessels	Coast Guard Vessels	Northern Gulf Total*	Central and Western Gulf Total
PM	226.98	18.53	245.50	129
NO_x	7,999.73	747.46	8,747.19	4,592
CO	785.62	73.67	859.29	451
VOC	71.01	6.56	77.57	41
CO_2	526,671.83	49,506.19	576,178.03	302,178
SO_2	1,715.87	125.28	1,841.15	967

*Note these emissions cover the whole Northern Gulf Region including the MMS' Eastern Gulf area. The northern Gulf military vessel estimates were adjusted to represent only activity in the central and western Gulf areas. For more information on how the emissions were spatially allocated see Appendix M.

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APPENDIX J

COMMERCIAL MARINE VESSELS

CMV emission estimates were calculated for vessels powered with marine diesel engines and residual-fueled steamships. The marine diesel calculation was performed by applying ton mileage emission factors to shipping lane activity data for the GOM, while the steamship emission estimates were developed by extrapolating data from EPA's 2000 National Emission Inventory (EPA 2002).

The coastal ports of the GOM include some of the busiest ports in the U.S. (e.g., Corpus Christi, Houston/Galveston, Beaumont, New Orleans, Biloxi, and Mobile), but the majority of commercial marine vessel traffic (thus estimated emissions) occurs in State waters or the Eastern portion of the Gulf of Mexico.

Estimating shipping lane activity requires in-depth evaluation of the actual shipping routes that vessels use. Although the GOM has a large number of shipping routes, most of the traffic is associated with a relatively smaller number of shipping fairways. Traffic into the Gulf occurs along two general paths; vessels using the Panama Canal to the south and vessels from Europe and the Middle Eastern Countries to the east.

Most of the traffic from the Panama Canal travels to the east of Cuba and up the east coast. Vessels from Panama that visit ports in the Western Gulf area travel along a shipping lane that only impacts the south western corner of the MMS Western Gulf area. As they approach land, they tend to travel near the shore or in the intercontinental waterway (neither are included in the current inventory) to their final destinations. The remaining traffic that uses the Panama Canal travels through MMS lease blocks and is included in this inventory effort.

Vessels coming from the Europe and the Middle East tend to enter the Gulf near the Florida Keys, and travel along the coast or in the intercontinental waterways (not included in this inventory effort) to destinations in the central and western portions of the Gulf.

The marine diesel emission factors developed for this study are compiled in Table J-1. These emission factors apply to all marine diesel engines (Category 1, 2, and 3) and are provided in terms compatible with available GIS data. These factors were developed using the emission factor equation created during EPA's marine diesel rulemaking and assumptions about the national fleet servicing U.S. ports. These emission factors were applied to shipping lane traffic data provided by the Army Corps of Engineer as a GIS data file (BTS 2000). It should be noted that shipping traffic associated with the approach to the LOOP were not included in this section, but were developed for Appendix F which addresses emission sources associated with the LOOP. To develop an estimate of CMV emissions for the portion of the Gulf that is of interest in this study, the ton miles for each shipping lane that transverses the MMS lease blocks were totaled and applied to the emission factors noted in Table J-1.

The CMV fleet also includes older steamships that burn residual fuel to generate steam which is used for propulsion. Steamships account for less than one percent of the CMV fleet. 2000 emission estimates were developed for steamships in the 2000 National Emission Inventory (EPA 2003). These steamship estimates were used to estimate emissions for the GOM by ratioing the national estimate to the Central and Western portions of the Gulf, based on cargo traffic provided by the Army Corps of Engineers (See Table J-2) (BTS 2000). This approach thus uses cargo traffic as a surrogate for emissions, and assumes that the proportion of cargo handled by residual-powered vessels is similar throughout the U.S.

Combined emissions for marine diesel engines and steamships are noted in Table J-3.

Table J-1. Emission Factors and Estimates for Marine Diesel Engines (tons/year).

MMS Gulf area ton mileage	3.6457×10^{10}					
Pollutant	VOC	CO	NO_x	PM	SO_2*	CO_2
Emission Factor (g/ton-nautical mile)	0.0041	0.0466	0.4727	0.0117	0.0792	31.3147
Emission Estimate	166.69	1,812.74	19,000.08	470.92	3,184.47	1,258,432.54

*For this study the fuel sulfur concentration was assumed to be 0.4%.

Table J-2. Steamship Ton-Miles and Emission Estimates (tons/year).

MMS Gulf area ton mileage	3.6457×10^{10}				
National ton mileage	4.0700×10^{12}				
Pollutant**	VOC	CO	NO_X	PM	SO_2*
National Steamship Emission Estimate	1,690.57	7,060.79	54,374.83	3,019.08	40,258.87*
MMS Gulf area emissions	15.14	63.25	487.06	27.04	360.62

* For this study the fuel sulfur concentration of residual fuel was assumed to be 2.7%.
**CO_2 was not one of the pollutants included in the 2000 National Emission Inventory.

Table J-3. Summary of CMV Emission Estimates (tons/year).

CMV Type	VOC	CO	NO_X	PM	SO_2	CO_2
Marine Diesel	166.69	1,872.74	19,000.08	470.92	3,184.47	1,258,432.54
Steamship	15.14	63.25	487.06	27.04	360.62	--
Total	181.83	1,935.99	19,487.14	497.96	3,545.09	1,258,432.54

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APPENDIX K

BIOGENIC/GEOGENIC SOURCES

The primary natural sources of air pollution that were evaluated for this Gulfwide study are: subsurface seeps of crude oil, subsurface seeps of natural gas (including methane hydrates), emissions from bacterial processes, and from ocean processes. Each of these source types presents unique problems in terms of characterization of the emission sources and estimating the associated emissions. Credible VOC emission estimates could only be developed for subsurface seeps of oil and N_2O emission estimates for bacterial processes.

Subsurface Seeps of Crude Oil

Subsurface seeps of oil, more commonly referred to as oil seeps, occur when crude oil deposits beneath the ocean floor escape into the ocean waters because of cracks and vents in the floor. Cracks can open and close as the result of several geological activities. The volume of oil seeping into the ocean can be relatively significant though. The total amount of oil that is released into the ocean does not, however, find its way to the surface and end up as air emissions. Some ocean-dwelling biota develop communities surrounding oil seeps and utilize the hydrocarbons as a source of nutrients. Other free floating organisms in the water column consume portions of the escaping oil as the material rises to the surface. Although these processes do mitigate the amount of oil that reaches the surface for possible volatilization, there is significant uncertainty and variability on the amounts that do reach the surface. Air pollutants that can be emitted from oil seeps include VOC, methane, CO_2, and air toxics. Based on the data found in the literature, only VOC emissions can be estimated at this time.

The MMS and other researchers have conducted a significant amount of work to study the extent of oil seeps in the GOM and off the coast of California. Much of this investigation has focused on the occurrence of communities of chemosynthetic organisms and oil slicks. Both factors have been shown to correspond to significant oil seep activity. A major study on the natural seepage of crude oil into the marine environment is being prepared by the National Academy of Sciences (NAS) and due to be released in the spring of 2002. Some preliminary information from this effort relates to the GOM. This NAS report and much of our research into emission estimates for oil seeps is making use of key papers and reports (MacDonald et al. 1993, MacDonald et al. 1995, MacDonald et al. 1996, Kennicutt et al. 1989, Mitchell et al. 1999).

Estimates have been made of the total quantity of oil seeping into various ocean waters based on studies of oil slicks both at the ocean level and from satellite and space shuttle photography. These data have been input to models capable of estimating overall oil seepage rates. Crucial variables in the models include wind speed, oil layer thickness, and the oil degradation half-life. Over the last 10 years several different and sometimes highly variable estimates of total oil seepage into the GOM have been prepared. With improvements in remote sensing technology, better estimates are being made possible. Some of the most recent work places oil seepage in the northern GOM at $2.5 – 6.9 \times 10^5$ barrels/yr (Mitchell et al. 1999). Converting to tons, the average estimate of seepage in the northern GOM is 73,000 tons/yr.

Using this figure, emissions can be estimated using either the oil seepage emission factor (105 lbs/barrel oil released) developed by the California Air Resources Board (CARB 1993) or the average mass volatilization from oil slicks predicted by the MMS open ocean weathering model (U.S. DOI, MMS 1998, Kirstein 1992). One model prediction showed that after 10 days time, 34% of the oil mass from a slick would have evaporated. The application of these methods results in similar mass emission estimates as shown below.

1) 73,000 tpy x 294 gal/ton x 1 bbl/42 gal x 105 lbs/bbl = ~26,827 tons/yr VOC

2) 73,000 tpy x 0.34 = 24,820 tons/yr VOC

For the purposes of this MMS non-platform inventory we will use an average of the two estimates (25,823.5 tons/yr). It should also be noted that none of the studies provided accurate definitions of the Northern Gulf, such that it was not possible to map the study area to MMS lease blocks. In which case it is assumed that these emission estimates are for the whole Northern Gulf area. When adjusted to represent only the Central and Western Gulf, the VOC emissions decline to 13,561 tpy (see Appendix M).

Subsurface Seeps of Natural Gas

The phenomena of natural gas seeps are very similar to that described above for oil. Gas vents can occur in the ocean floor thereby releasing gas of geologic origin into the water column. Quantitative information on the levels of methane that may be seeping into GOM waters could not be located during the literature search conducted for this project. For this reason, it was not possible to formulate an estimate of emissions for this source type. Methane can also be formed by sediment bacteria; however, quantification of these rates is very difficult to determine. Studies are underway to evaluate biological methane generation and scavenging; however, no estimates of air emissions are currently available.

Methane released through ocean floor vents or from biological processes can also form methane hydrates. Hydrates form as frozen structures at low temperatures and high pressures, conditions indicative of the deep waters of the GOM. Methane hydrates represent an overall storage of both methane and carbon. Sporadic emissions of methane could occur under specialized conditions such as ocean floor landslides, elevations in water temperature, or reductions in water pressure; however, these occurrences are expected to be minimal. Methane hydrates have not generally been viewed as sources of concern for methane air emissions (EPA 1993).

Bacterial Processes

Bacterial process sources include plankton producing dimethylsulfide (DMS) and sediment bacteria producing methane. DMS released from protozoa and zooplankton has been linked to the formation of tropospheric aerosols and cloud condensation nuclei, which can result in negative influences on global warming (Gabric et al. 1993). Estimates of DMS flux from the GOM range from 9.2 μmol/m^2/day (in January) to 13.8 μmol/m^2/day (in July) (Andreae 1997). Note, DMS is not one of the pollutants included in this study. As described previously, sediment bacteria methane generation and potential atmospheric release is not well characterized and cannot be estimated for the purposes of this inventory.

Nitrous oxide (N_2O) is produced by deep-water bacteria, and is transferred to the atmosphere through upwelling and air-sea transfer mechanisms (Nevison et al. 1995). Bouwman et al. (1995) compared several earlier inventories of ocean N_2O to create a gridded annual N_2O inventory available as part of the Global Emission Inventory Activity (GEIA) data set. Based on this information (Nevison et al. 1995), total annual emission for the GOM study area have been estimated to be 3,710 tons N_2O –N/Year. When adjusted to represent only the Western and Central Gulf, the N_2O estimate is 1,948 tons.

Ocean Processes

The action of ocean processes can emit a diverse variety of air pollutants. In addition to being a source of air pollutants, marine processes can also remove nitrogen and carbon species from the atmosphere and function as a sink for these compounds (Hood et al. 2000).

Carbonyl sulfide (COS) is emitted from dissolved organic matter in ocean water through photochemical processes. In deep water, transition, and upwelling zones, the COS flux can range from 16 nmol/m^2/d to 72 nmol/m^2/d (Andreae and Ferek 1992). COS is the longest-lived sulfur species in the atmosphere. Since it is not altered in the troposphere, it has the potential to be transported into the stratosphere and increase the sulfate aerosol layer, thereby affecting the Earth's radiation budget. Note, COS is not a criteria pollutant nor is it a greenhouse gas therefore, it is not one of the pollutants included in this study.

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APPENDIX L

PLATFORM CONSTRUCTION AND REMOVAL

During the construction and removal of offshore oil platforms, a variety of vessels are needed to transfer equipment, materials, and platform structures, as well as workers and technicians. The methods used to estimate emissions from these vessels were adapted from an earlier MMS study, *Emission Inventories of OCS Production and Development Activities in the Gulf of Mexico – Final Report* (Coe et al. 2003).

Platforms that were installed or removed during 2000 were identified by querying MMS' platform structure database. This database provided latitude and longitude coordinates of each for each of the identified platforms and was linked to the master MMS database to obtain water depth information at each of the identified platforms. MMS staff also helped quantify the number of pilings associated with each of the platforms that was constructed or removed in 2000.

As the vessels involved in platform construction and removal activities are similar to those discussed in Appendix C of this report, many of the same assumptions about vessel characteristics and operations were used. For example, the amount of time spent and fuel used in hoteling, cruising, and at full power for each of the vessel types was assumed to be the same as in Appendix C (see Table L-1).

Table L-1. Fuel Usage and Time Spent by Vessels in Support of Platform Construction and Removal.

Vessel Type	Mode	Fuel 1000 L/hr	Fraction of Time	Weight Fuel L/hr
Barge	Hotel	0.01	0.5	40
	Cruising	0.04		
	Full	0.07	0.5	
Crew	Hotel	0.01	0.1	69
	Cruising	0.04	0.1	
	Full	0.08	0.8	
Supply	Hotel	0.01	0.45	75.5
	Cruising	0.08	0.1	
	Full	0.14	0.45	
Tug	Hotel	0.04	0.33	213.33
	Cruising	0.21	0.33	
	Full	0.39	0.33	

The number of pilings and the water depth at the platform were used to estimate the total number of hours that each of the four vessel types operated in support of platform construction and removal activities as noted in Table L-2. Some of the daily hour estimates are larger than 24 hours suggesting that more than one vessel is supporting platform construction and removal activities.

Table L-2. Daily Fuel Consumption and Operating Hours by Vessel Type.

	Fuel Consumption (L/day)			Operating Hours (hrs/day)		
	Water Depth (Ft)			Water Depth (Ft)		
Vessel Type	<300	300 to 600	>600	<300	300 to 600	>600
Barge	1514	1514	7919	37.85	37.85	197.98
Crew	2907	2907	2907	42.13	42.13	42.13
Supply	2735	2735	2735	36.23	36.23	36.23
Tug	1367	2790	5323	6.41	13.08	24.95
Total	8523	9946	18884	122.61	129.28	301.28

To estimate the number of activity days associated with the construction or removal of each of the identified platforms, the depth and piling data compiled by MMS for individual platforms were applied to estimates of the number of activity days associated with different water depths and platform pilings. These activity data were summed for the MMS central and western Gulf areas and are noted in Table L-3.

Table L-3. Total Days for Construction or Removal of Platforms in the Year 2000.

	Water Depth (Ft)			Total Days
	<300	300 to 600	>600	
Total Days to Install or Remove	4,023	332	413	4,768

The daily operating hours, noted in Table L-2, for each vessel type were applied to the total days for construction or removal of platforms as noted in Table L-3 to estimate total hours of operation by vessel type. These estimates are summarized in Table L-4, below.

Table L-4. Estimate of Total Operating Hours by Vessel Type for Platform Construction and Removal.

Vessel Type	Daily Hours			Total Hours			Total Hours
	Water Depth (Ft)			Water Depth (Ft)			
	<300	300 to 600	>600	<300	300 to 600	>600	
Barge	37.85	37.85	197.98	152,270.6	12,566.2	81,763.68	246,600.4
Crew	42.13	42.13	42.13	169,490.7	13,987.3	17,399.87	200,877.9
Supply	36.23	36.23	36.23	145,733.8	12,026.75	14,960.99	172,721.6
Tug	6.41	13.08	24.95	25,778.66	4,341.942	10,305.01	40,425.6
			Total	493,273.8	42,922.2	124,429.5	660,625.5

To use the EPA's latest marine diesel emission factors, it is necessary to estimate the operating load of each of the vessel types included in Table L-4. It was assumed that the time in mode and operating load for each mode for each vessel type were similar to support vessels discussed in Appendix C. These operating loads and time in mode values are summarized in Table L-5. As in Appendix C, the operating load for each vessel type was weighted based on the amount of time spent in each mode. These weighted operating loads are noted in Table L-5.

Table L-5. Weighted Operating Loads for Each Vessel Type.

Operating Mode	% Total power	Fraction of Time in Operating Mode				Component Load Factors			
		Barges	Crew	Supply	Tugs	Barges	Crew	Supply	Tugs
Hoteling	0.1	0.5	0.1	0.45	0.33	0.05	0.01	0.045	0.0330
Cruising	0.55	0.0	0.1	0.1	0.33	0.0	0.055	0.055	0.1815
Full Power	1	0.5	0.8	0.45	0.33	0.5	0.8	0.45	0.3300
					Weighted Load Factor	0.55	0.865	0.55	0.5445

These weighted operating loads, in conjunction with the typical horsepower ratings noted in Appendix C, were used to calculate hourly emission factors for each of the vessels. These estimates will be comparable with other vessel estimates where time in mode data were not available. These emission factors were developed using the following emission equations from the U.S. EPA's *2000 Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* (EPA 2000) in order to derive a representative emission factor.

$$E\ (\text{g/kW-hr}) = A * (\text{Load Factors})^{-x} + B$$

Where:

E is the power-based emission factor;

Constant A, intercept B, and exponential x noted in Tables C-3 to C-6 were obtained from Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

For SO_2, it is necessary to first calculate *Fuel Consumption* using the following equation:

Fuels Consumption (g/kW-hr) = 14.12/(fractional load) + 205.717

It is assumed that diesel fuel, modeled after distillate fuel oil #2, is used in marine applications. Such fuel is assumed to have a sulfur content of 0.4 percent. This percentage of sulfur in the fuel should be multiplied by the *Fuel Consumption* calculated above, to estimate the *Fuel Sulfur Flow* as noted below:

Fuel Sulfur Flow (g/kW-hr) = Fuel Consumption (g/kW-hr) * 0.004

The fuel sulfur flow is thus applied to the following equation to obtain a SO_2 emission rate:

SO_2 Emission Rate (g/kW-hr) = A* Fuel Sulfur Flow (g/kW-hr) + B

Where A and B are dimensionless constants provided in Table 5-1 of the U.S. EPA *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* report (EPA 2000). The emission factors reported in these tables do not always agree with the coefficients, due to round-off error.

These emission factor calculations are noted in Tables L-6 through L-9 below.

Table L-6. Barge Emission Factors.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	kW	kg/hr	lbs/hr	Hours	Tons
PM	0.2696	1.5	0.2551	0.0059	229.7	0.06	0.14	246,600	16.83
NO_x	10.7573	1.5	10.4496	0.1255	229.7	2.47	5.45	246,600	671.60
SO_2*	1.8449	N/A	0	1.998	229.7	0.42	0.93	246,600	115.18
CO	1.5233	1	0	0.8378	229.7	0.35	0.77	246,600	95.10
VOC	0.1635	1.5	0	0.0667	229.7	0.04	0.08	246,600	10.21
CO_2	728.7818	1	648.6	44.1	229.7	167.38	369.0	246,600	45,499.44

Average HP 308 = 229.7 kW
For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table L-7. Crew Boat Emission Factors.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	kW	kg/hr	lbs/hr	Hours	Tons
PM	0.2624	1.5	0.2551	0.0059	357.9	0.09	0.21	200,878	20.80
NO_x	10.6056	1.5	10.4496	0.1255	357.9	3.80	8.37	200,878	840.57
SO_2*	1.7702	N/A	0	1.998	357.9	0.63	1.40	200,878	140.30
CO	0.9686	1	0	0.8378	357.9	0.35	0.76	200,878	76.76
VOC	0.0829	1.5	0	0.0667	357.9	0.03	0.07	200,878	6.57
CO_2	699.5827	1	648.6	44.1	357.9	250.41	552.0	200,878	55,446.79

Average HP 480 = 357.9 kW
For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table L-8. Supply Boat Emission Factors.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	kW	kg/hr	lbs/hr	Hours	Tons
PM	0.2696	1.5	0.2551	0.0059	647.3	0.17	0.38	172,722	33.22
NO_x	10.7573	1.5	10.4496	0.1255	647.3	6.96	15.35	172,722	1,325.66
SO_2*	1.8449	N/A	0	1.998	647.3	1.19	2.63	172,722	227.35
CO	1.5233	1	0	0.8378	647.3	0.99	2.17	172,722	187.72
VOC	0.1635	1.5	0	0.0667	647.3	0.11	0.23	172,722	20.15
CO_2	728.7818	1	648.6	44.1	647.3	471.72	1,039.9	172,722	89,810.65

Average HP 868 = 647.3 kW
For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

Table L-9. Tug Boat Emission Factors.

Pollutant	E (g/kW-hr)	Exponent (x)	Intercept (B)	Coefficient (A)	kW	kg/hr	lbs/hr	Hours	Tons
PM	0.2698	1.5	0.2551	0.0059	1665.9	0.45	0.99	40,426	20.03
NO_x	10.7620	1.5	10.4496	0.1255	1665.9	17.93	39.52	40,426	798.90
SO_2*	1.8470	N/A	0	1.998	1665.9	3.08	6.78	40,426	137.11
CO	1.5387	1	0	0.8378	1665.9	2.56	5.65	40,426	114.22
VOC	0.1660	1.5	0	0.0667	1665.9	0.28	0.61	40,426	12.32
CO_2	729.5917	1	648.6	44.1	1665.9	1215.42	2,679.5	40,426	54,160.61

Average HP 2234 = 1665.9 kW
For SO_2 fuel sulfur flow (g/kW-hr) = 14.12/fractional load + 205.717 fuel sulfur concentration. For this study the fuel sulfur concentration was assumed to be 0.4%.

The above hourly emission factors presented in Tables L-6 through L-9 were applied to the total hour estimates noted in Table L-3 to estimate total annual emissions associated with the construction and removal of offshore oil platforms. These estimates are summarized in Table L-10.

Table L-10. Emission Summary by Vessel Type.

Pollutant	Barges (tpy)	Crew Boats (tpy)	Supply Boats (tpy)	Tugs (tpy)	Total (tpy)
PM	16.83	20.80	33.22	20.03	90.88
NO_x	671.60	840.57	1325.66	798.90	3,636.73
SO_2	115.18	140.30	227.35	137.11	619.94
CO	95.10	76.76	187.72	114.22	473.81
VOC	10.21	6.57	20.15	12.32	49.26
CO_2	45,499.44	55,446.79	89810.65	54,160.61	244,917.48

Further study is needed to determine whether these estimates double count with the support vessels emission estimates included in Appendix C of this report. Support vessels utilize many of the same vessels used in platform construction and removal such as barges, crew boats, supply ships and tugs. This inventory does not include drill ships used for setting the platform pilings as they were not included in Coe et al. (2003), and it was thought they would double count with the drill ship estimates included in Appendix B of this report, further study is needed to confirm this assumption.

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APPENDIX M

SPATIAL ALLOCATION METHODS FOR NON-PLATFORM SOURCES

In this section, the approaches used to spatially allocate emissions are discussed for each of the source categories. Mostly, Geographic Information System (GIS) tools were used to develop these allocations, and the data were disaggregated to individual lease blocks or latitude and longitude coordinates when available.

The GIS data which were used to spatially allocate emissions were obtained from MMS and the Army Corps of Engineers (ACE). It should be noted that the GIS calculations that were implemented in developing these methods to spatially allocate emissions, particularly for length of shipping lane and surface area, do not necessarily match the original length/area values. Theoretically, a waterway can be disaggregated to the individual lease blocks it travels through. As a quality check, the individual segments should add up to the original length of the shipping lane. The sum of the individual lengths do not always match the original ACE data. ACE has been contacted to better appreciate how the data set was developed. This issue of the lengths not matching introduces to the inventory a relatively small error, however, between 2 and 5 percent.

Biogenic/Geogenic Sources

Emissions from biogenic/geogenic sources have been calculated for VOCs and N_2O. For VOC emitted from subsurface crude oil seeps, emissions were allocated equally throughout the federal waters in the Gulf, based on the surface area of each lease block, as noted in the equation below. For N_2O emissions from bacterial processes, an estimate that covers the entire Gulf was derived from Nevison et al. (1995). This report did not clearly indicate the geographic area for which the emissions were estimated; therefore the emissions were equally distributed throughout the Gulf based on the surface area of each lease block.

$$E_{Bi} = E_{BG} * (S_i/S_{TNG})$$

Where:

E_{Bi} = Biogenic/geogenic emissions for lease block i
E_{BG} = Biogenic/geogenic emissions for Northern Gulf area
S_i = Surface area of lease block i
S_{TNG} = Surface area of total Northern Gulf lease blocks

Commercial Fishing

Commercial fishing locations were provided by the National Marine Fisheries Service (NMFS). Reef and shrimp fishing operations are delineated by NMFS statistical zones. NMFS also provided latitude and longitude coordinates for line fishing operations. Emissions were spatially allocated for these three fishing activities by overlaying a GIS shape file of the MMS lease blocks onto the NMFS fishing zone data, as noted in the equation below.

$$E_{CFi} = E_{CFz} * (S_i/S_{CFz})$$

Where:

E_{CFi} = Commercial fishing emissions for lease block i
E_{CFz} = Commercial fishing emissions for NMFS area z
S_i = Surface area of lease block i
S_{CFz} = Total surface area of NMFS area z

The associated NMFS zone was attributed to each lease block within the NMFS area, as noted in Figure M-1. Where a lease block was included in two NMFS areas, the assignment was made proportional to the area of the NMFS zone that the lease block occupied. For example, a lease block AB is split between NMFS Zone 15 and Zone 16. Seventy five percent of lease block AB is included in Zone 15 and 25 percent of lease block AB is in Zone 16. In this example, emissions associated with NMFS zones 15 and 16 would be split in lease block AB, proportional to the area with which each zone is associated.

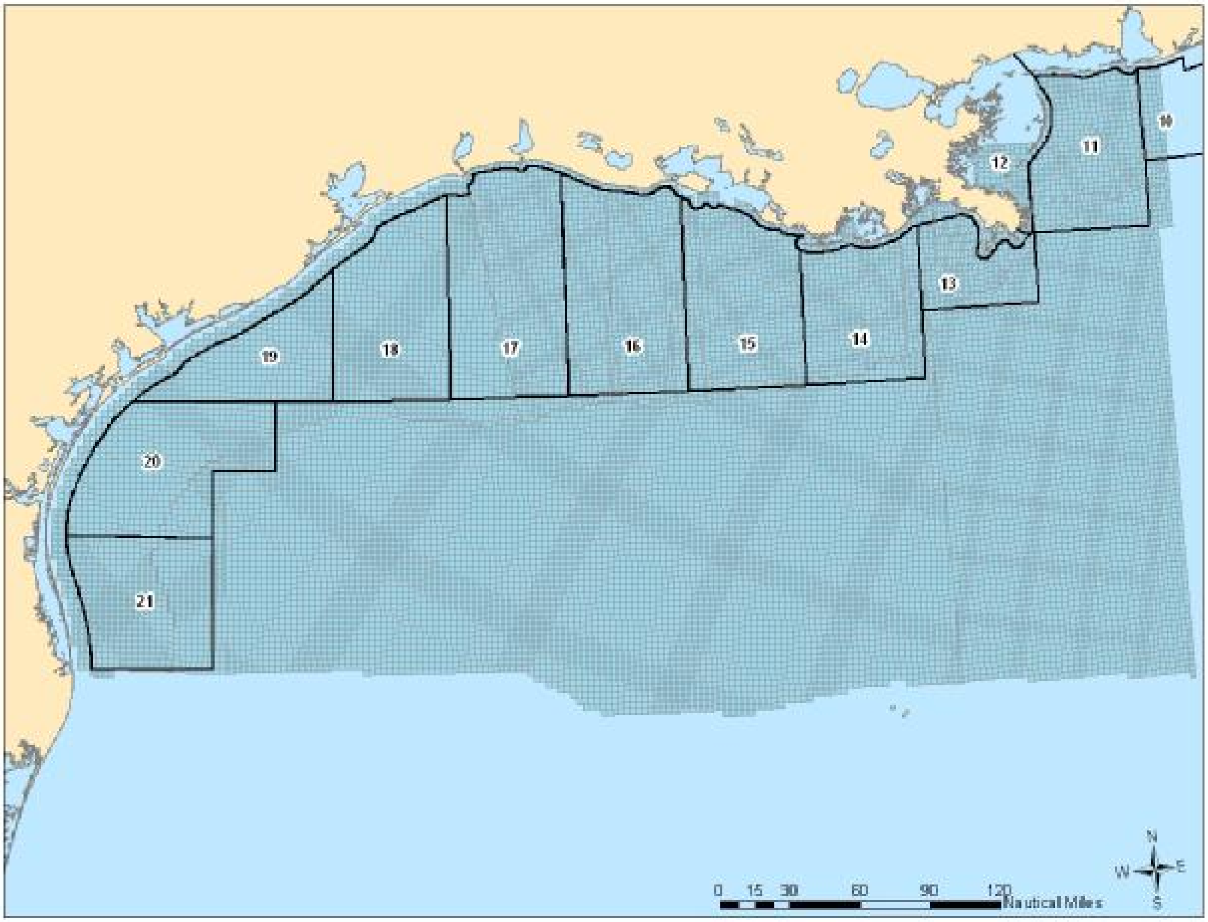

Figure M-1. NMFS Fishing Zones with MMS Lease Blocks.

Commercial Marine Vessels

The commercial marine vessel (CMV) shipping lane activity data were obtained from the ACE as a GIS data set. Emissions were apportioned to individual links included in the ACE data set based on the cargo miles attributed to the links, which is the amount of cargo handled per link multiplied by the length of the link. Figure M-2 shows the CMV shipping lanes included in the ACE dataset. Shipping lanes in state waters were included, though they were not included in the emission estimates for the inventory, to show how shipping lanes in federal waters match up to shipping lanes in state waters.

The data used were provided as thousand cargo tons, in terms of tons upward and tons downward along the link. The MMS lease blocks were defined by their protraction and block numbers, and mapped onto the GIS shipping lane data set; and emissions were apportioned to individual lease blocks based on the amount of cargo miles lying within the lease block boundaries, as noted in the following equation.

$$E_{CMVi} = CM_i * EF_{CMV}$$

Where:

E_{CMVi}	=	Commercial marine vessel emissions for lease block i
CM_i	=	Total cargo miles for lease block i
EF_{CMV}	=	Commercial marine vessel emission factors

As mentioned earlier, there are some minor problems with the segment lengths reported in the ACE data set. To try to minimize the error, the original lengths were used whenever possible. The length of each waterway segment was calculated as a portion of the entire waterway, and these percentages were applied to the original length of the waterway to estimate the length of each segment. If only part of a waterway was contained within the MMS area, then length was based on the GIS calculations.

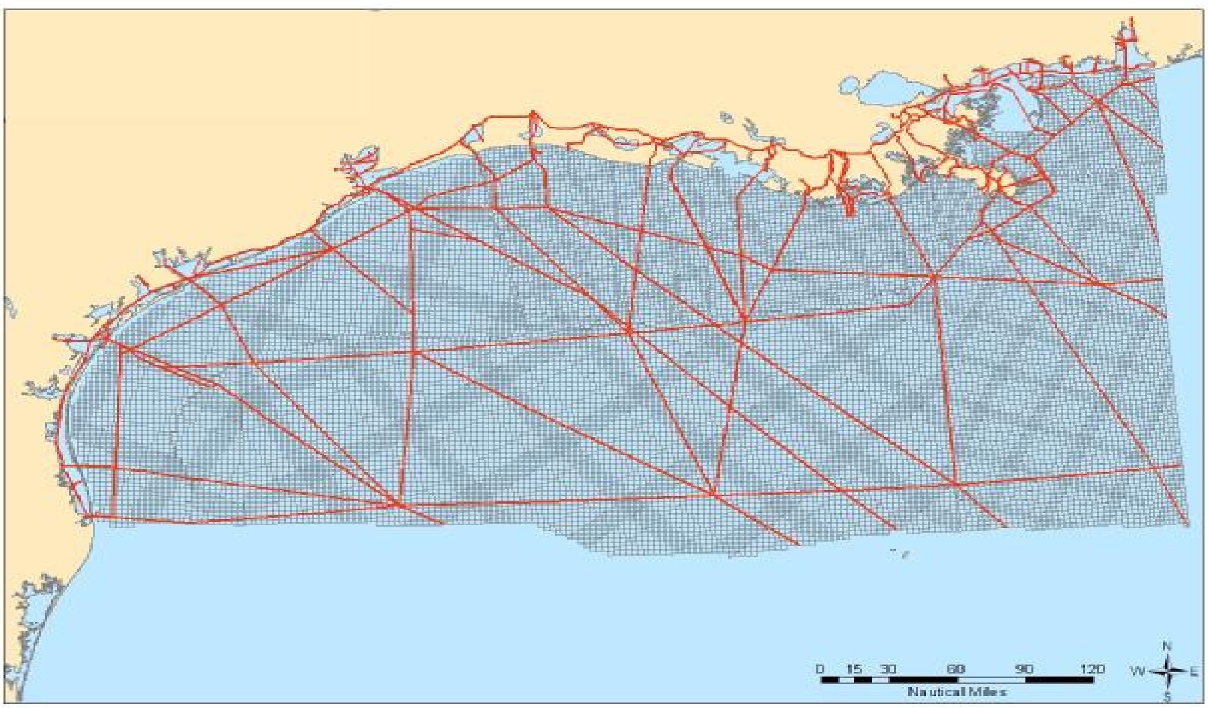

Figure M-2. Commercial Marine Vessel Shipping Lanes and Lease Blocks Associated with the MMS Western and Central Gulf Areas.

Drilling Rigs

The drilling rig activity provided by MMS included the specific lease blocks where drilling occurred as noted in Figure M-3 below. Emissions were calculated for each drilling operation as described in Appendix B and assigned to the lease blocks where the drilling occurred.

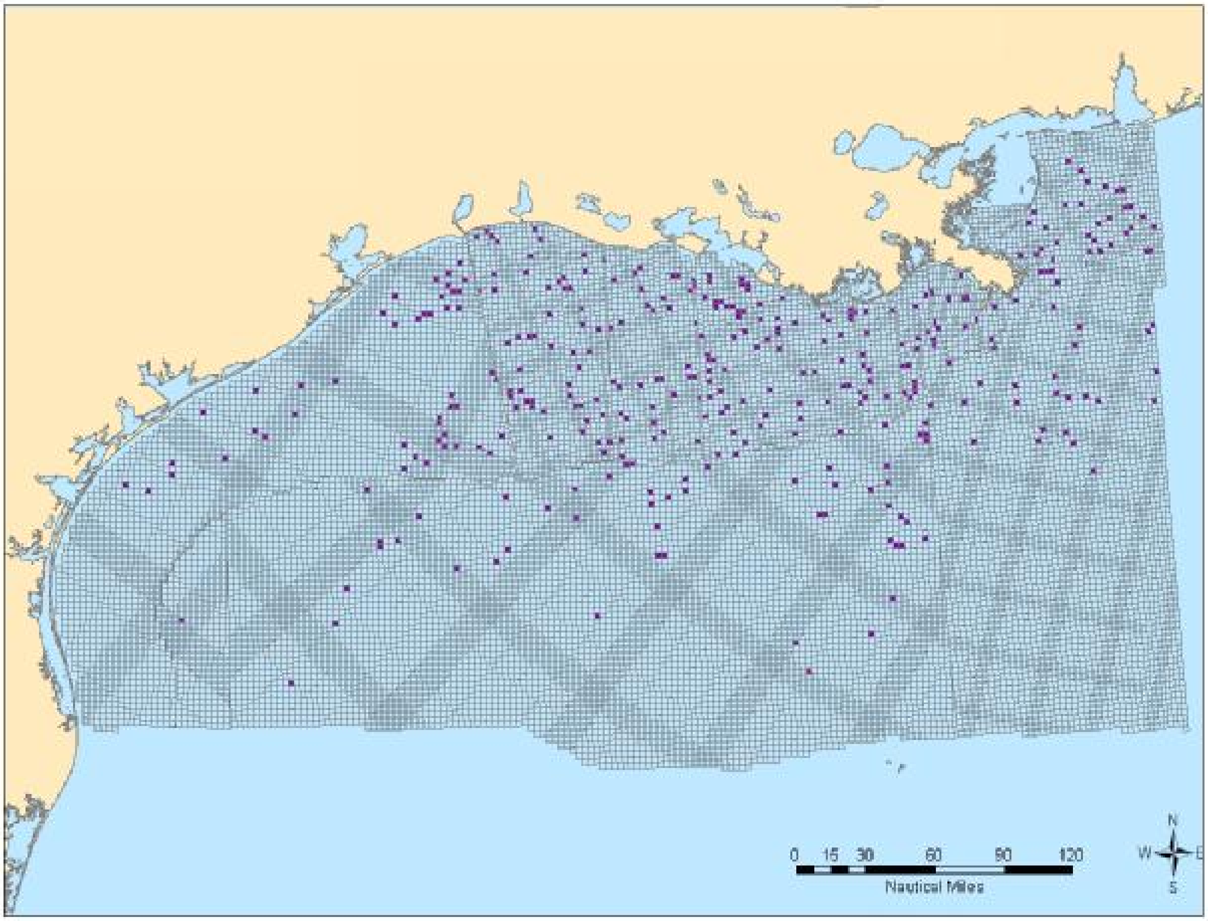

Figure M-3. Location of Drilling Operations and MMS Lease Blocks for 2000.

LOOP

The Louisiana Offshore Oil Platform (LOOP) website provided detailed geographic data identifying the shipping approach used by vessels, and the latitude and longitude coordinates for the platform itself (see Figure M-4).

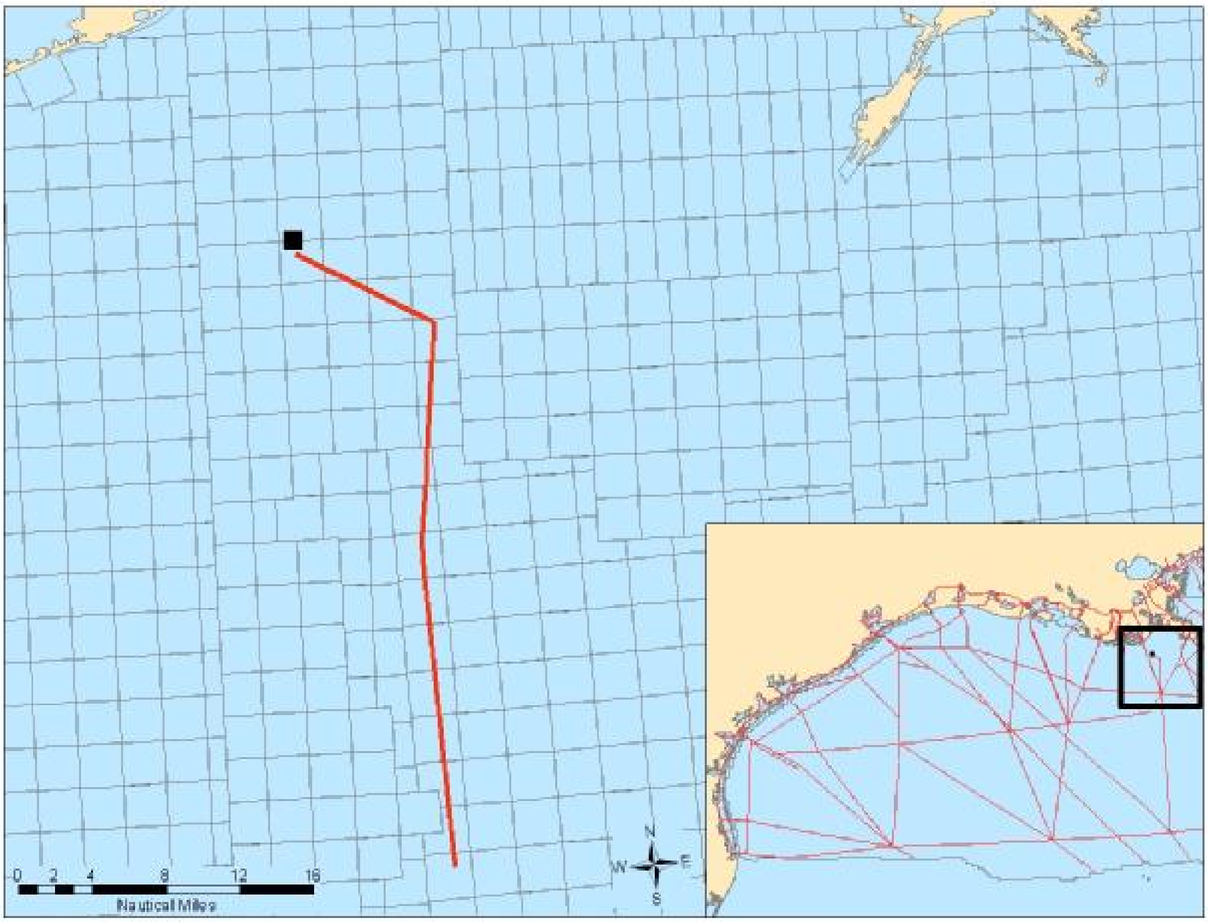

Figure M-4. Shipping Lane Approach and Location of LOOP.

Emissions were spatially allocated to lease blocks by matching the shipping routes and platform coordinates to the MMS GIS shape file of the Central Gulf lease blocks. All emissions associated with the platform were assigned to the platform coordinates, while transit emissions associated with the approach and departure of tankers were assigned to lease blocks that intersect the approach lane as noted in the following equation.

$E_{LPi} = E_{LP} * (L_i/L_T)$

Where:

E_{LPi} = Tanker emissions for lease block i
E_{LP} = Total emissions for tanks approaching and departing the LOOP
L_i = Length of shipping land in lease block i
L_T = Total length of approach and departure shipping lane

Military Vessels

Military activity data and emissions were estimated Gulfwide, and were allocated equally throughout the federal waters of the Gulf (Eastern, Central and Western Gulf areas), as noted in the equation below. This allocation was made based on the surface area of the lease blocks.

$E_{MVi} = E_{MV} * (S_i/S_{TNG})$

Where:

E_{MVi} = Military vessel emissions associated with lease block i
E_{MV} = Total military vessel emissions for total northern Gulf area
S_i = Surface area of lease block i
S_{TNG} = Surface area of total Northern Gulf lease blocks

Pipelaying Operations

MMS maintains GIS data for pipeline construction and maintenance activities. These 2000 activity data were used to map emissions to the individual lease blocks by intersecting the MMS lease block shape file with the MMS pipeline data. Emissions were attributed to individual lease blocks based on the length of pipeline constructed or maintained within the boundaries of the lease blocks, as noted in the following equation. Figure M-5 shows the location of the pipeline lengths and the associated MMS lease blocks.

$E_{Pi} = L_{Pi} * EF_P$

Where:

E_{Pi} = Emissions associated with pipelaying for lease block i
L_{Pi} = Length of pipe constructed or maintained in lease block i
EF_P = Emission factor for pipelaying activity

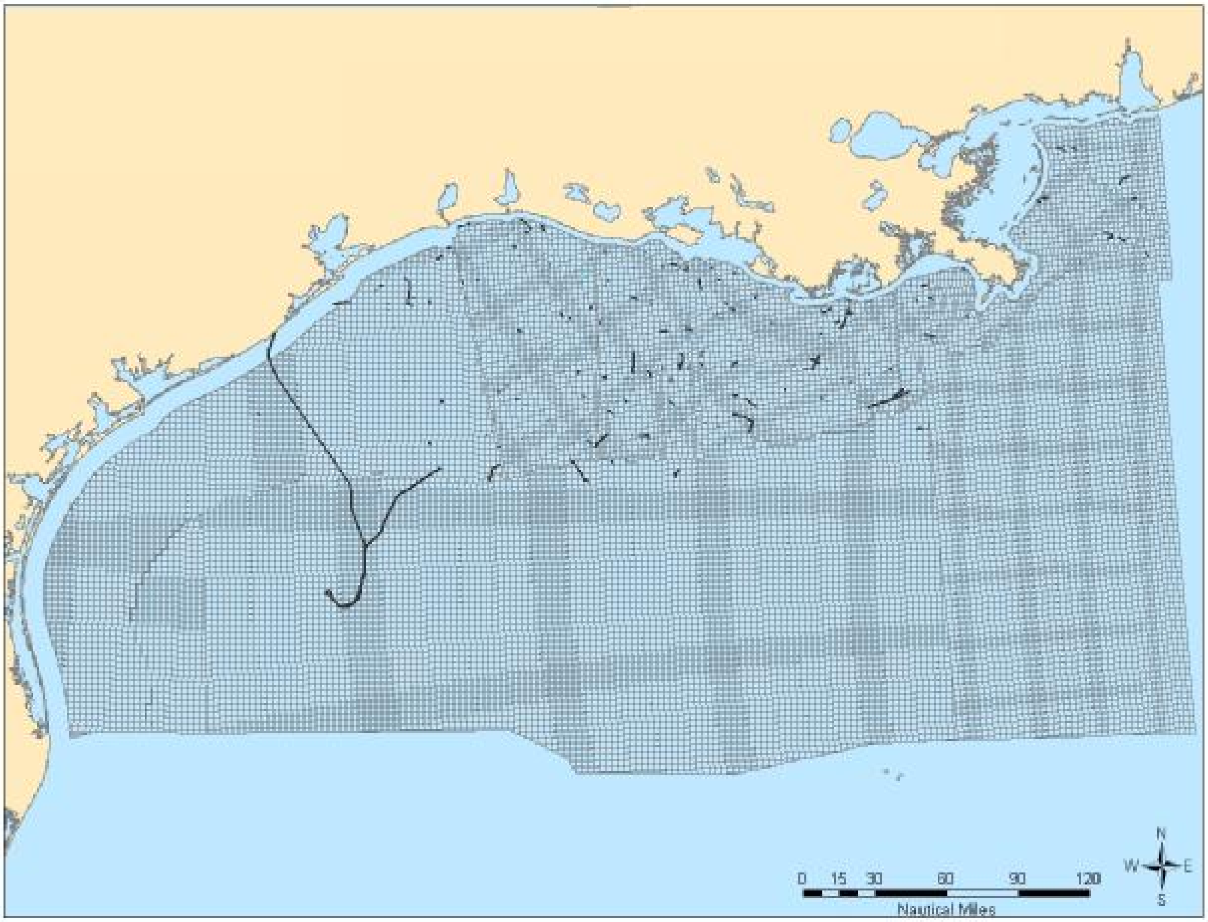

Figure M-5. Pipeline Locations and MMS Lease Blocks.

Support Helicopters

Helicopter emissions can be apportioned by assigning emissions to lease blocks with active platforms that have heliports, as most of the emissions associated with support helicopters occurs while the craft is near or at the platform, as noted in the equation below. The active platforms with helipads are noted in Figure M-6.

$$E_{Hi} = E_H * (P_{Hi}/P_{HT})$$

Where:

E_{Hi} = Support helicopter emissions associated with lease block i
E_H = Total helicopter emissions
P_{Hi} = Number of platforms with heliports in lease block i
P_{HT} = Total number of platforms with heliports

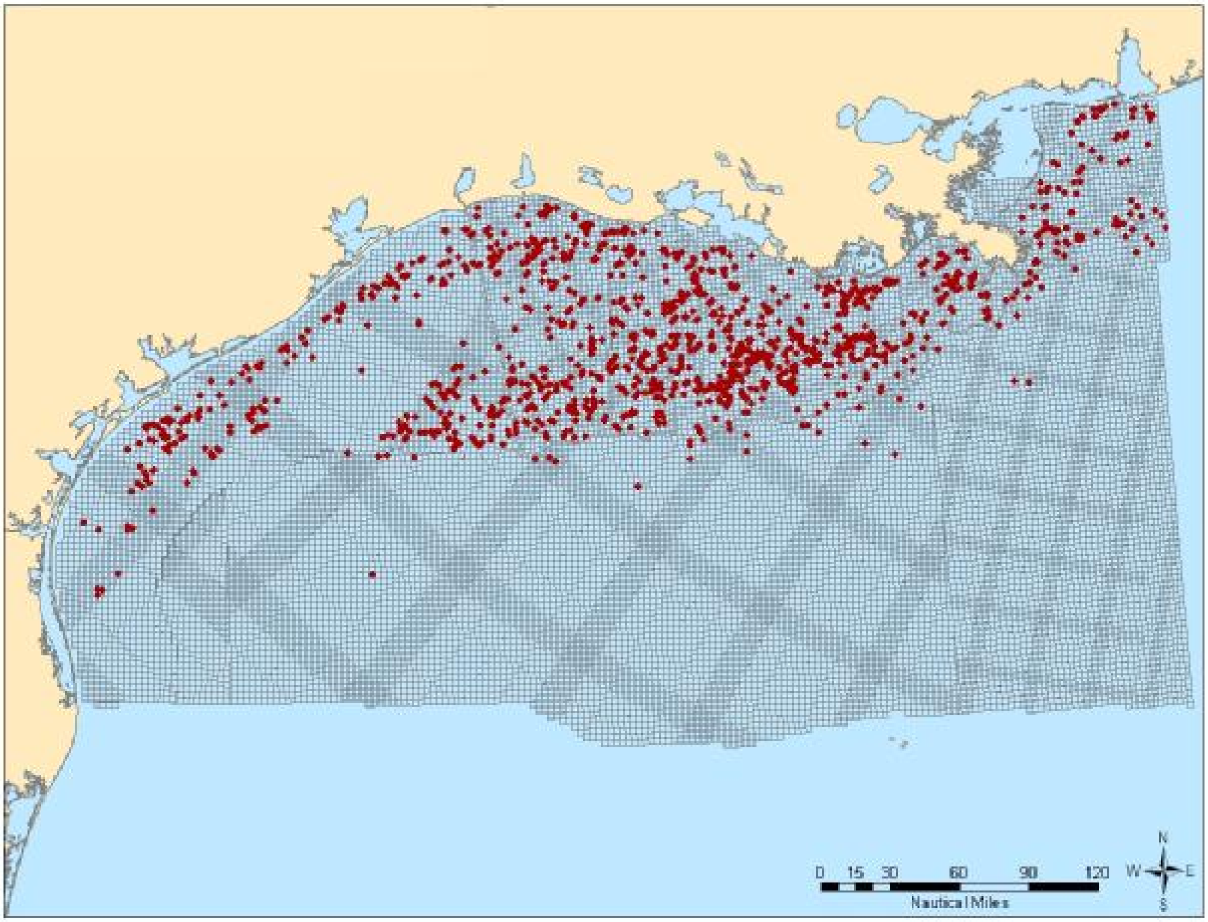

Figure M-6. Location of Active Platforms with Helipads.

Support Vessels

In order to allocate support vessel emissions to the lanes that these vessels use to and from local ports, emissions were first disaggregated into hoteling and underway activities. Hoteling emissions occur while the vessel is waiting at the offshore platform. During this period, the diesel engine is operating under less than optimal design parameters, generating elevated NO_x and PM emissions. The period that vessels are hoteling can vary significantly depending upon the material that is being off loaded. In some cases, support vessels stop their marine diesel engines during hoteling. Unfortunately, there is currently no information that can help quantify the extent of this practice. For the purpose of this inventory, it was assumed that 25 percent of support vessel emissions occur while hoteling. The hoteling emissions were applied equally to each active platform. The platform latitude and longitude coordinates were used to spatially define the emission point.

The remaining 75 percent of support vessel emissions were assigned to links from the platforms to the local ports. To allocate support vessel underway emissions, individual links were defined for each active platform. The first step was to define the closest home port for each platform. The following ports were defined as home ports for support vessels:

- Corpus Christi, TX;
- Freeport, TX;
- Houston/Galveston, TX;
- Beaumont, TX;
- Morgan City, LA;
- New Orleans, LA;
- Biloxi, MS; and
- Mobile, AL.

Next, the pathway from the home port to the platform was defined. Once the links were defined (see Figure M-7), the length of each link occurring in each lease block was summed, and emissions were apportioned to individual lease blocks, based on the fraction of the total miles of shipping lane, as noted in the following equation:

$$E_{SVi} = E_{SV} * (S_{Li}/S_{LT})$$

Where:

E_{SVi} = Support vessel emissions associated with lease block i
E_{SV} = Total underway emissions associated with support vessels
S_{Li} = Sum of the lengths of all shipping lanes within the boundaries of lease block i
S_{LT} = Total sum of all shipping lanes in the western and central areas of the Gulf

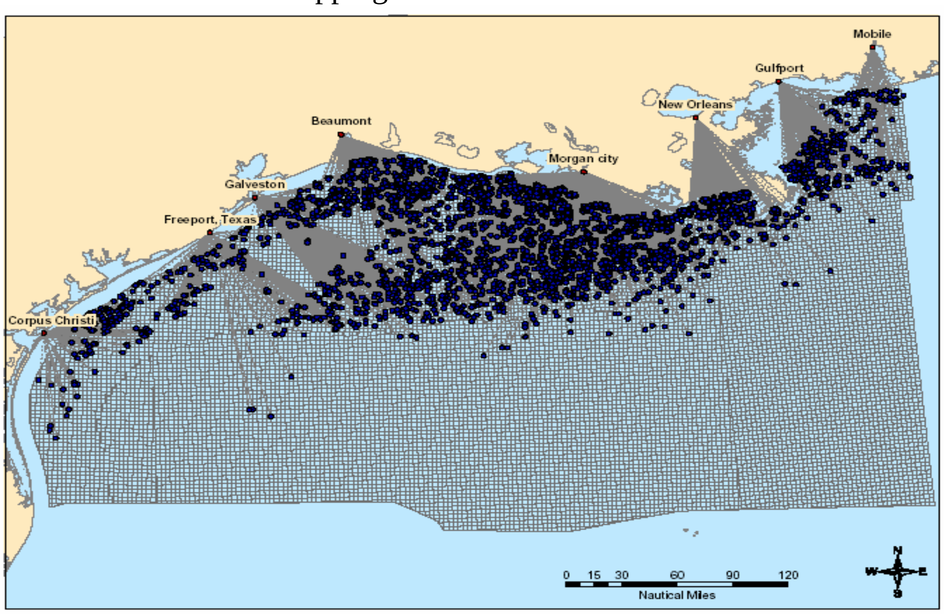

Figure M-7. Support Vessel Fairways.

Survey Vessels

For survey vessels, emissions were developed for the inactive lease blocks. Emissions were allocated to each inactive block based on the surface area of the lease block, as noted in the following equation. The lease blocks that were flagged as inactive during the 2000 period are noted in Figure M-8.

$$E_{Si} = E_S * (S_{ii}/S_{ti})$$

Where:

E_{Si} = Survey vessel emissions associated with lease block i
E_S = Total survey vessel emissions
S_{ii} = Surface area of inactive lease block i
S_{ti} = Total surface area of all inactive lease blocks

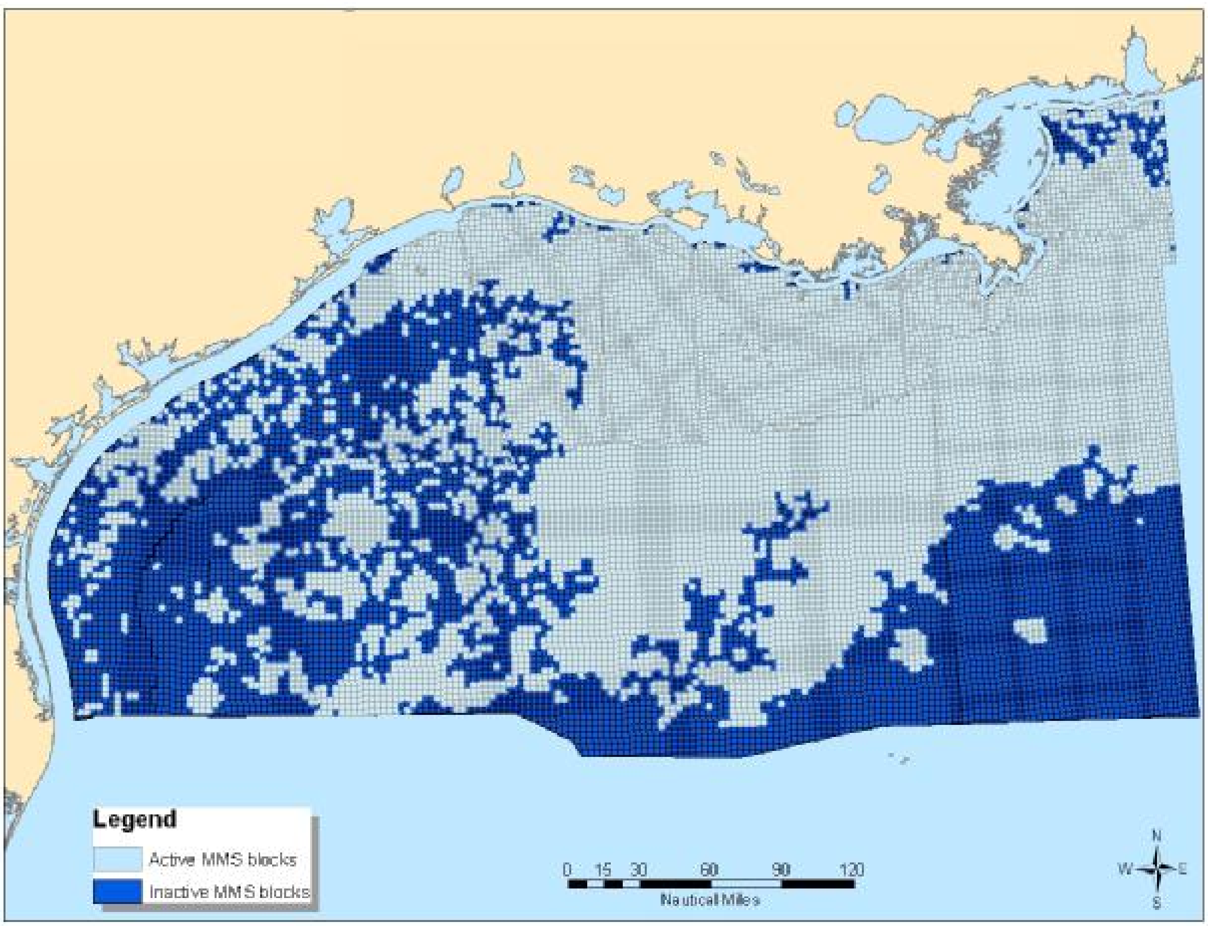

Figure M-8. Inactive MMS Lease Blocks.

Vessel Lightering

Vessel lightering occurs in three designated zones in the Gulf and is monitored by the U.S. Coast Guard. Ballasting and tanker emissions were spatially allocated to each zone using the latitude and longitude coordinates for the centroid of the lightering zone. Escort vessel emissions were spatially allocated by mapping the vessel fairway from the centroid of the lightering zone to the nearest port, as noted in Figure M-9. Emissions were assigned to individual lease blocks that overlapped with the escort vessel fairway based on the length of the fairway within the boundaries of the individual lease block as noted in the equation below.

$$E_{VLi} = E_{VLZ} * (L_{Si}/L_{SZ})$$

Where:

E_{VLi} = Vessel lightering emissions associated with lease block i
E_{VLZ} = Total vessel lightering emission from lightering zone z to port
L_{Si} = Length of lightering vessel fairway in lease block i
L_{SZ} = Total length of escort vessel fairway from lightering zone z to port

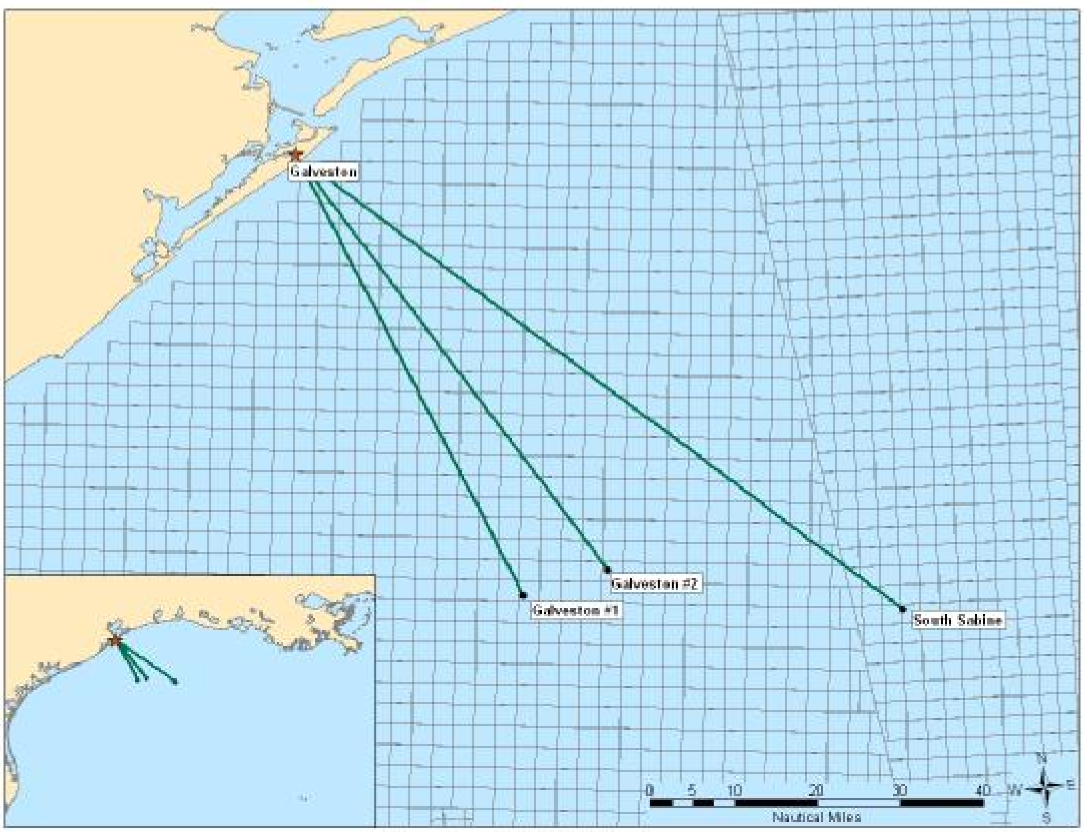

Figure M-9. Vessel Lightering Area and Shipping Fairway to Port.

Platform Construction and Removal

Emission estimates were developed for six different platform sizes and matched to individual platforms that were either constructed or removed during 2000. The emission estimates were spatially assigned to the platform's latitude and longitude coordinates (see Figure M-10) based on the number of pilings of each platform as discussed in Appendix L.

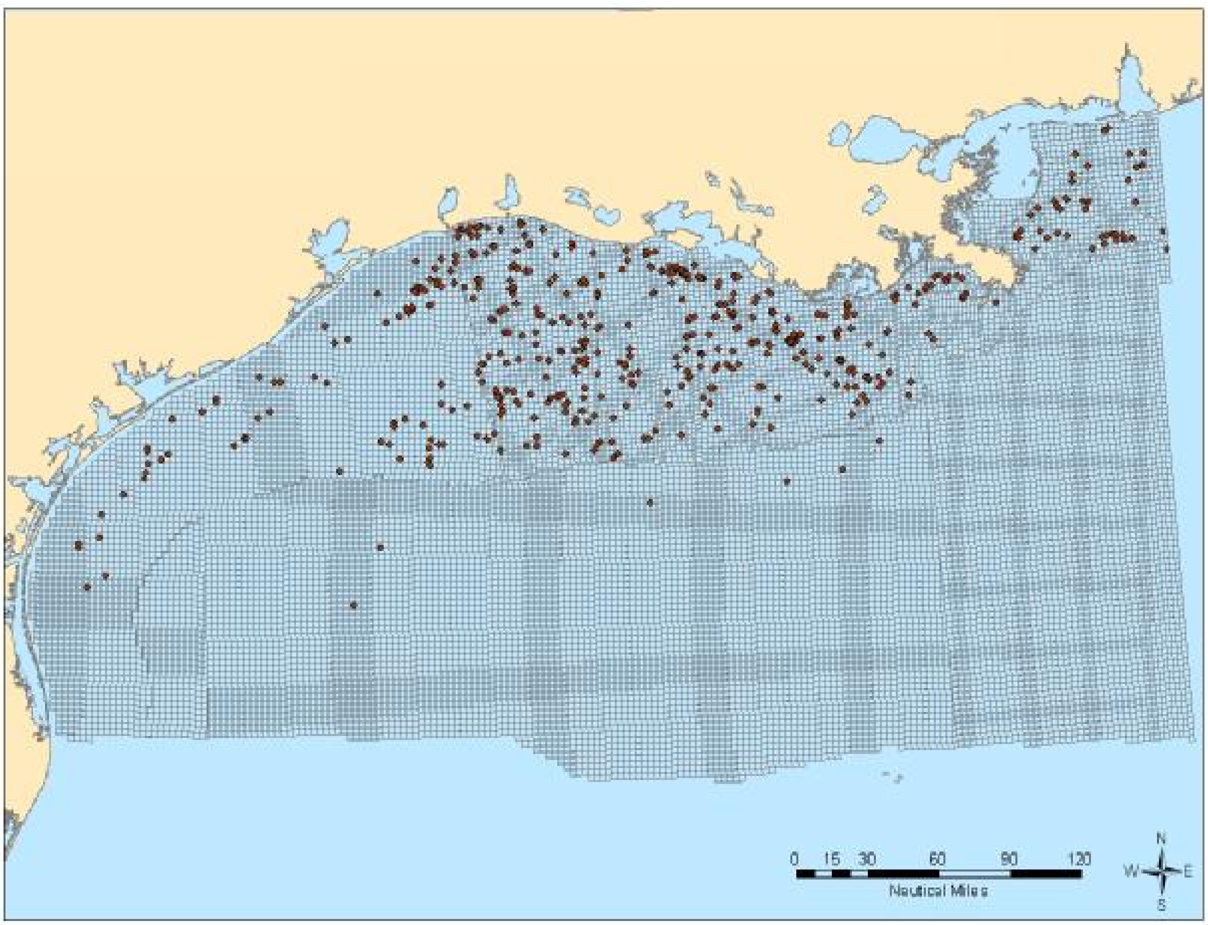

Figure M-10. Location of Platform Construction and Removal During 2000.

References

Nevison, R., R.F. Weiss, and D.J. Erickson III. 1995. Global oceanic emissions of nitrous oxide. Journal of Geophysical Research, vol. 100, no. C8, pp. 15,809-15,820.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.

MMS Securing Ocean Energy & Economic Value for America